Water Power

INTERNATIONAL DEVELOPMENT OF HYDRO-ELECTRIC POWER

PRICE 2/6 JULY 1957

HYDRO-ELECTRIC

POWER IN INDIA

The Madras Government Irrigation and Power scheme depends on hydro-electric stations such as Mettur Dam shown. Metrovick generators, transformers, switchgear and protective apparatus, etc. are used extensively on the system. Mettur station contains 4 Metrovick 12,500 kVA generators.

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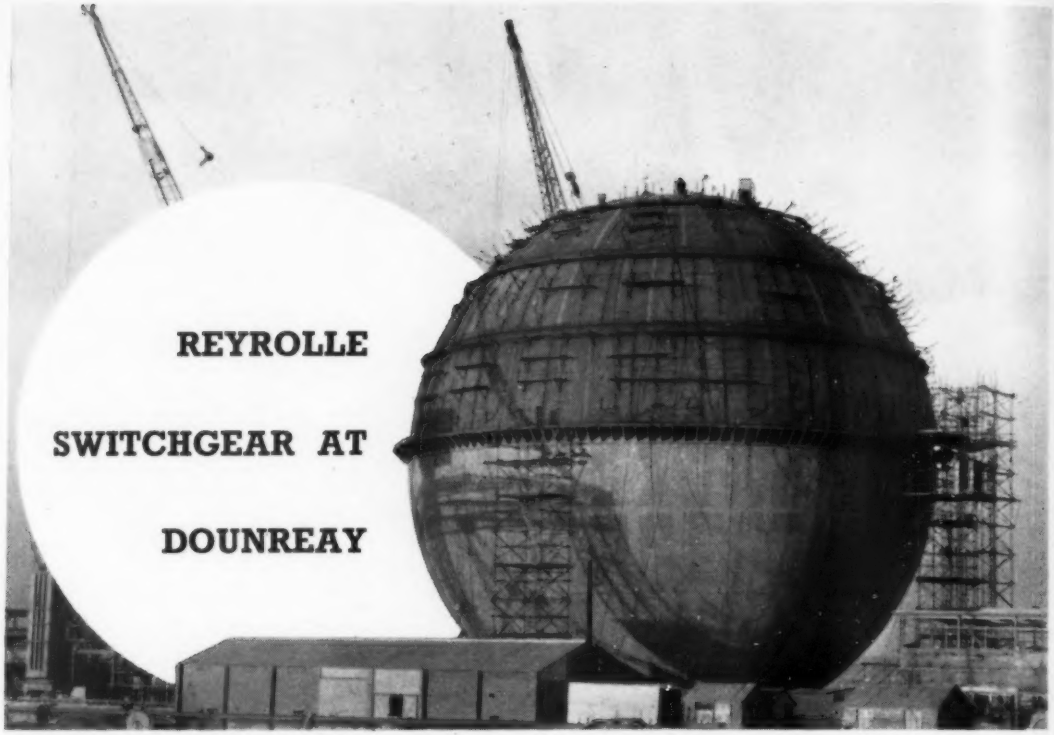

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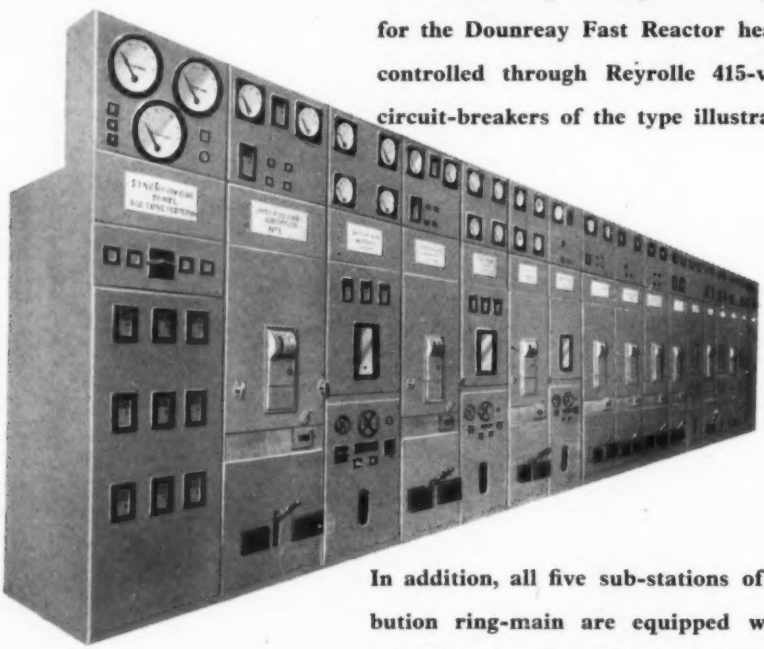

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WATER POWER

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WATER POWER

A technical journal devoted to the study of all aspects of Hydro-Electric Development

Water Power in the U.S.S.R.

A DETAILED report has now been issued by the group of six British engineers, all interested in hydro-electric development, which was appointed by the Institutions of Civil, Mechanical and Electrical Engineers to visit the U.S.S.R. with a view to studying progress in that country. This visit was arranged under the aegis of the Soviet Relations Committee of the British Council and it is understood that a team of Russian engineers will be making a return visit to this country shortly, during which they will be shown around British hydro-electric installations. An account of the preliminary impressions of this team was given in WATER POWER, December 1956 (page 467) and a list of the personnel on page 405 of the November issue.

The delegation travelled some 4,400 miles while in Russia and were shown various hydro-electric schemes, research laboratories and factories in which hydro-electric equipment was being manufactured. The estimated hydro-electric potential of the Soviet Union, based on 1,477 rivers, is about 1,500 billion kWh per annum, but 80% of this total refers to the sparsely populated lands east of the Ural mountains. Of this huge potential only about 1·5% had been developed by 1955 and despite the large stations at present being erected only 4% would be harnessed by 1960. The most spectacular developments seen by the delegation were those on the Volga, which is planned to have a total of twelve generating stations with an installed capacity of 10,264 MW. Seven of these stations are already in operation and the eighth is expected to be ready by 1960, by which time the installed capacity will be 6,324 MW. The Kuibishev station, which will be described in WATER POWER shortly, has an installed capacity of 2,100 MW, generated in 26 units of 105 MW each. Its reservoir will be the longest in the whole series of Volga stations and will have a length of 600 km. and cover an area of about 9,500 sq. km. Other particulars of this station given by the delgates include: average output per annum, 11·3 x 10^9 kWh; average annual load factor, 68·5%; capital cost per kW installed, £133; annual fixed charges per kW (at 6%), £5·72; total charges per kWh, 0·3248d.

In constructing stations both on the Volga and Dnieper it has been possible to make substantial economies in the cost of plant by using the same general design for each station, so that virtually the equipment can be manufactured on the mass-production principle.

A scheme of exceptional interest visited by the delegation was that concerned with the Sevan lake, situated in the south of the mountain range known as the Little Caucasus. This lake, 1,416 sq. km. in extent, is fed by 28 rivers and has only one outlet—the river Rasdan, on which it is proposed to erect a sequence of power stations. The unique feature of this scheme centres on the method of using the lake Sevan, for although the total inflow amounts to 1,320 million cu. m. per annum, such is the high rate of evaporation that the annual outflow is only 110 million cu. m. per annum. It is proposed, therefore, to reduce the level of the lake by draw down over a period of years so that the surface exposed to evaporation will be reduced to one-sixth of its present area. This ingenious measure is estimated to have the effect of increasing the flow in the river Rasdan from 110 to 700 million cu. m. per annum.

The members of the delegation appear to have been deeply impressed with the scale of the hydro-electric operations in the U.S.S.R. which, after all, form only part of the drive to secure a power production that is now considered to be commensurate with the needs of a modern state. The schemes in general are of the multi-purpose variety, embracing navigational improvements, irrigation and water supply, in addition to the provision of power. From what they saw and were told by Soviet engineers it would appear that the constructional methods employed differ little from those followed in other parts of the world. Great importance is attached to research and the members were left with the firm conviction that a uniformly

high standard was being achieved in the three hydraulic laboratories they visited. Of the two works they visited, one manufacturing turbines and the other generators, they found both to be equipped with up-to-date machine tools and concluded that Russian industry was well capable of designing and making any types of plant likely to be required. Great effort was directed to design simplification to save material and construction time, two examples of this being the use of water-lubricated, rubber-lined lower guide bearings for turbines and the method used to support the thrust-bearing assembly on a fabricated skirt sitting on the top cover of the turbine. They found Soviet engineers eager to exchange experiences with western engineers and considered that such exchanges would by no means be a one-way arrangement, as they obviously had technical know-how to grapple with any difficulty that might arise.

Addition to Bridge River

B.C. ELECTRIC have awarded new contracts, totalling nearly $27·5 million, in connection with the second stage of the Bridge River development. One of these, for $25 million, has been gained by Northern Construction and J. W. Stewart Limited for the construction of a new 190 ft. high dam on the Bridge River and a new power house on Seton Lake. The second, for $2·5 million, has been awarded to Canadian Westinghouse Company for four 62,000 kW generators to be installed in the power house by 1960. The existing Bridge River station, which harnesses 248,000 h.p., is already the largest in the B.C. Electric system, and the new scheme will increase the power capacity by a further 345,000 h.p.

The new dam, 45 miles downstream from the 282 ft. high La Joie dam, will be about 1,000 ft. thick at the base. These works will necessitate the construction of a new two-lane highway above the dam, and a total of some 40 miles of roads in the area will also need to be reconstructed at a higher level. The present bridge will be abandoned and replaced by a new bridge spanning the new dam.

A 1,000 ft. long diversion tunnel has already been completed to permit work to begin on the site. The power house will be 280 ft. long, 60 ft. wide and 70 ft. high.

In addition to the dam and power house, Northern Construction and J. W. Stewart's contract includes the construction of a switchyard, switching station, penstock, penstock anchors, footings, valve house, and the intake structure.

Hydro Power in the Nuclear Age

MR. A. A. FULTON, General Manager of the North of Scotland Hydro-Electric Board, in an address given recently to the Dundee Rotary Club, stated that if atomic power alone were used to meet the varied electricity demand of the North of Scotland at the present time, the cost of production would be about 1·25d. per kWh instead of the 0·64d., which was what it cost the Hydro Board to produce its water power in 1956. In 1980, despite the claim that by that date the production costs of base-load energy by nuclear power will have fallen to no more than 0·40d. per kWh, the production cost of all the Board's requirements by nuclear power would still be as much as 1d. per kWh. Therefore even if the cost of water power rises, there would still be quite a margin between the Board's hydro generating costs and this figure.

He also pointed out that although some energy loss was involved in pumped-storage schemes they did provide a cheap and convenient means of converting unwanted base-load power into valuable peak-load energy. In consequence there was ample room for extended water-power developments in the nuclear age, particularly of the pumped-storage type.

International Hydrology Conference

THE International Union of Geodesy and Geophysics is to hold its Eleventh General Assembly at Toronto from September 3-14, 1957, and that part of the Union which is probably of the greatest interest to water-power engineers, namely the International Association of Scientific Hydrology, is arranging a programme of papers on:—(a) the role of evaporation in the hydrological balance-sheet; (b) methods of forecasting the behaviour of streams, with particular reference to extreme discharges, whether low or high; (c) the roles of vegetation and cultivation of the soil in the hydrological cycle; (d) hydrological measurements; and other subjects.

The Secretary General of the International Association of Scientific Hydrology is Professor L. J. Tison, 61, rue des Ronces, Gentbrugge, Belgium, but the appointment of delegates and the selection of papers are made by the national sub-committees. It should be noted that the dates given above have been changed from those announced earlier.

Blaenau Ffestiniog Pumped-Storage Scheme

THE Central Electricity Authority of Great Britain has awarded The British Thomson-Houston Company the contract, valued at nearly £1 million, for the design, manufacture, testing and installation of four 75,000-kW, 16,000-volt generator/motor units for the first major pumped-storage scheme in the country and, it is believed, the largest of its kind in the world. This is at Blaenau Ffestiniog in North Wales, for which the consultants are Freeman, Fox & Partners, and Kennedy & Donkin.

The scheme will enable the best use to be made of the power generated by nuclear and coal-fired power stations which are most economical when operated continuously day and night, and this new installation will permit low-demand electricity to be stored in the form of high-head water for meeting the heavy demands made during peak-load periods. There is a head of 900 ft. between the upper and lower storage basins and the scheme will enable 300 MW to be contributed to the C.E.A. network within a matter of minutes.

Rainfall Control in Australia

A SUGGESTION that Australia's Scientific and Industrial Research Organisation should apply its knowledge of rainmaking techniques to relieve the drought over much of Australia was made in the House of Representatives in Canberra recently by a N.S.W. member. However, the Minister in charge of the Re-

search Organisation, Mr. Casey, told members that he could not promise any artificial rainmaking within the next twelve months. Mr. Casey said the organisation was not yet ready to apply the techniques it had evolved on any appreciable scale. There had been only one large-scale controlled experiment. This was in the Snowy Mountains area of south-eastern Australia, and it had produced a very satisfactory proven increase in rainfall for that area. Mr. Casey said he believed Australia was leading the world in rainmaking techniques, but more aircraft were needed for this work. He added that he was discussing this matter further with the Federal Treasurer, Sir Arthur Fadden.

Glen Canyon Contract Awarded

THE U.S. Department of the Interior has awarded the contract for the construction of the Glen Canyon dam to the Merritt, Chapman & Scott Corporation of New York, who submitted a bid of $107·9 million. This dam, which will be the largest on the Upper Colorado river, will be 720 ft. high and 1,500 ft. long, and will impound some 28 million acre ft. of water. The resulting reservoir will extend 180 miles upstream and the associated power house will have a capacity of 900 MW, generated in eight sets. Two diversion tunnels are being constructed, one on each bank of the river, and ultimately these will be arranged as spillway outlets capable of discharging floodwater at the rate of 276,000 cusecs. Work on the west-bank diversion tunnel was begun some months ago, the contract having been awarded to the Mountain States Construction Company of Denver.

British Hydromechanics Open Day

THE recent Open Day of the British Hydromechanics Research Association bore testimony to the ever-increasing range of work undertaken by this young and vigorous organisation. Within the hydroelectric field several investigations are in progress. Two problems are being studied, in collaboration with Sir Alexander Gibb and Partners, in connection with the Kariba scheme. An air model has enabled improvements to be suggested in the shape of the intake and of the bend in which the sector gate is accommodated, and a water model has provided information on the formation of vortices at the intakes. For the same consulting engineers experiments have also been carried out on a model of the deep sluices and spillway for Roseires dam on the Blue Nile. An outdoor water model of the Ffestiniog pumped-storage project is being built, as well as an indoor air model, to study flow conditions in the intake and upper bend at Stwlan for both directions of flow. These tests are being undertaken in collaboration with James Williamson and Partners and Freeman, Fox and Partners on behalf of the Central Electricity Authority.

The percolation of water under a dam was demonstrated by the electrical analogue method, using carbon-loaded conducting paper cut to the desired profile. Work has been commenced on cavitation, and much interest was displayed in a precision deadweight manometer developed and installed in two cavitation tunnels in Government Research Laboratories.

The work of the Association on the hydraulic transport of solids has reached impressive proportions, as has the work on centrifugal pumps, and work continues on an expanding scale on hydraulic transmissions, pump valves, and seals and glands.

On the lighter side we were treated to a repetition of the TT motor-cycle race of a year or two ago, in which a series of coins ran, apparently unaided, round a closed circuit of water-filled perspex pipe, but this year the track was more elaborate and the number of "competitors" greater. There was also an air-lift "perpetual motion" machine which reminded us agreeably of Maskelyne's Mysteries.

Further New Zealand Progress

MORE hydro-electric projects are being investigated in the north-eastern section of the North Island of New Zealand. Another New Zealand hydro announcement is expected soon on a project for building a power dam on the Rangitiki near the New Zealand North Island town of Matahina in the Bay of Plenty district.

During the past year engineers, surveyors and drillers have checked foundations and investigated possible dam sites. Mr. S. M. J. Smith, engineer in charge of investigations in the area, says that survey work on three likely sites at Matahina has been completed. Another likely site at Kopuriki is still being studied.

Surveys for other possible sites on the Whakatane and Waimana rivers are also being pushed ahead. Although some investigations have already been made the main work is being concentrated on the building of access roads. Because of the rugged nature of the country along the Whakatane River horses will be extensively used.

Preliminary work on the investigation of sites near Murupara is going steadily forward and access roads are being built. Mr. Smith stated that investigations in this area would extend from Murupara to the Napier-Taupo road. Survey work in the Opotiki area is also in progress and similar work on the Motu River is reported to have proved encouraging.

The Struggle Against Sedimentation

IN May 1956 WATER POWER published an article by Monsieur H. Duquennois on "New Methods of Sediment Control in Reservoirs" in which the author discussed the general principles of scouring techniques and in particular their application to the Iril-Emda dam in Algeria. It may be recalled that a series of small scouring valves were introduced to bypass the main sluices and allow the denser sediment-laden currents to be drawn off at the base of the dam while obviating the necessity of opening the main sluices. It was also proposed to erect a small dam, equipped with rapidly opening sluice gates, at the head of the reservoir in order to induce scouring waves in times of low water and thus eliminate accumulations of sediment by "approach" as well as "transport" scouring methods. It is estimated that the capacity of the reservoir will eventually be maintained indefinitely at 80% of its original capacity whereas without these techniques 50% of the capacity would be lost in some 40 years or so.

The success of these methods can now be further

estimated from a study of the third annual report on the Iril-Emda dam (Compte rendu No. 3. Lutte contre la Sedimentation des Barrages Reservoir — "The Struggle Against Sedimentation in Reservoirs") published by Electricité et Gaz d'Algérie. The report shows that although the 1955-56 hydrological year proved to be of a very exceptional nature, the efficacy and the economics of the scouring procedures adopted were entirely confirmed and much valuable experience was gained. In point of fact, it is estimated that 50% of the total sediment entering the reservoir was removed by the scourage procedure so that well over 2,500,000 cu. m. of storage capacity was saved. The figures might have been even higher but for an extraordinarily sudden and violent flood in October which resulted in the scour valves being blocked for several weeks, until they could be cleared by naval divers. During this period scouring was carried on by the intermittent opening of the main sluices—a procedure which proved to be less efficient—and there was a consequent setback in the desilting programme. However, the real importance of this report lies in the account it gives of the vigorous and experimental approach that has been made to a very difficult problem, and, above all, of the detailed analyses that are given of density currents, sediment profiles and underwater topography—all of which are helping to pioneer the way towards controlling the sedimentation evil.

Proposals for Wanganui River, New Zealand

A NEW source of water power is to be investigated in New Zealand involving the Wanganui river on the east coast of the North Island. Mr. Goosman, the Minister of Works, stated that the reach between Parikino and Taumarunui would possibly be developed for hydro-electric power in two, three, or four stages by means of a series of dams ranging from 100 to 275 ft. in heigth. The damming of the river at several points to form a chain of lakes, stretching over 80 miles, he considered, would add to the scenic attractions of the river, while the estimated potential of 350,000 kW would be a very worthwhile contribution to the North Island power supply.

Hume Station in Operation

THE new hydro power station at Hume dam on the river Murray was put into service recently. This is an interstate enterprise in which the State Electricity Commission of Victoria and the Electricity Commission of New South Wales are jointly interested, the operating costs being shared equally by the two States. There will eventually be two generators, each of 25 MW capacity, one for Victoria and one for New South Wales. At present, however, only one generator is operating, and its output is being fed into the Victorian system by a new 66 MV transmission line running from Hume to Wodonga.

The high-voltage supply line to link Hume power station with the New South Wales system is now complete and it is expected that the second generator will be installed this month. By the end of 1958 the storage capacity of the Hume reservoir is expected to be 2½ million acre ft. and it is estimated that this will permit an average annual electricity production of 230 million kWh. In ten years time, when an additional volume of water will be diverted from the Snowy scheme into the Murray, the annual production of the station will be increased to 260 million kWh. It should be understood that the main purpose of Hume reservoir is to store water for irrigation, electricity production taking second place.

Hydro Station to Operate by Radio Control

TWO new hydro-electric power-stations to be built in New South Wales will be able to operate under water in time of flood. Each station will be radio-controlled by engineers many miles away. One will be built at the Keepit dam, near Gunnedah. It will produce 20 million kWh per annum when it is finished in 1960 and will be remotely controlled by engineers at Newcastle, more than 100 miles away. The second power station, to be built at Warragamba dam, 50 miles from Sydney, will be operated by remote control from Sydney. Warragamba dam station will be built by the English Electric Co. Ltd. at a cost of £A.1,000,000. Tenders are to be called soon for the construction of the Keepit dam and associated power station.

Hydro Power in Uganda

WHEN the Uganda Electricity Board purchased the Kikagati hydro-electric station from Kagera Mines, a few months ago, their first task was to recover a runner which had dropped from one of the three machines nine years ago. As the mining company did not require the whole of the power developed no attempt had been made to recover the runner. After dismantling the turbine, steel rods were used to locate the missing runner, and it was found to be lying directly under the draft tube, covered by about 10 ft. of mud and silt which were in turn under a 9 ft. depth of water.

The problem of removing the silt was solved by the use of a pump kindly lent by the Kampala fire brigade. After agitation of the mud by means of a jet of water from the pump, the mud was removed by a portable sludge pump and part of the runner was then exposed. Mr. I. H. Wilson, of Wilson, Laity & Company, civil-engineering contractors, descended through the draft tube wearing a diving suit, and succeeded in attaching a wire rope to the runner, which was thus recovered and found to be in good condition.

The Kikagati hydro-electric scheme is on the Kagera River, about 90 miles from the mouth of the river which flows into Lake Victoria on its western shore. It is designed to take a further set and this will be installed in due course, making the total capacity 1,000 kW.

The Uganda Electricity Board's recently published Ninth Annual Report refers to the investigation which is being made into possible power developments on the River Nile between Owen Falls and Lake Kyoga. The consulting engineers, Sir Alexander Gibb & Partners and Messrs. Kennedy & Donkin, consider 500 MW of capacity to be available and trial bores are now being put down to test the conditions at a site some miles downstream of the Owen Falls.

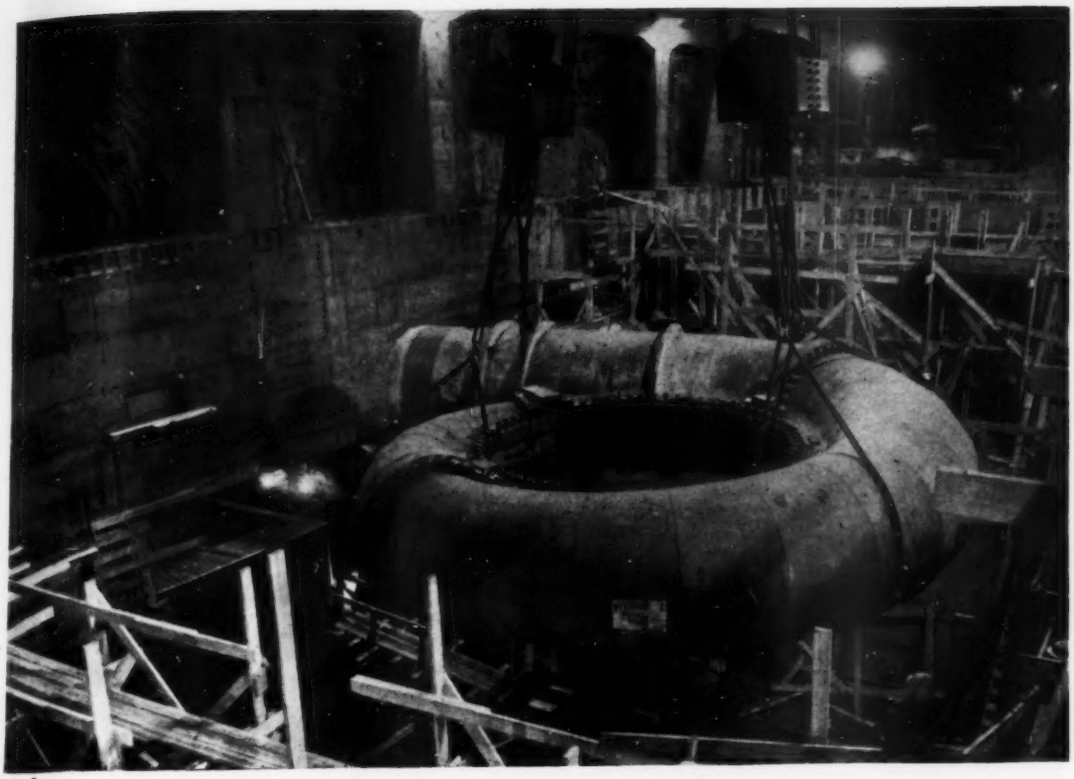


Fig. 15. Placing the scrollcase of No. 2 turbine

The Bersimis-Lac Cassé Scheme

The development of the first stage of this important Canadian project is described by O. Perryman

PART TWO

AFTER careful cost investigations, it was evident that an underground power house would be the most suitable economically, as the great mass of solid rock afforded by the mountain so near to the river would be ideal for withstanding the tremendous surge pressures set up in the penstocks and hence eliminate the necessity to build large-diameter ones in the open.

The generator hall has been excavated to a length of 565 ft., 65 ft. wide and 80 ft. high. The access tunnel is 270 ft. long, 36 ft. wide and 30 ft. high, and was driven full face to grade from ground elevation 468 ft. to a point 50 ft. from the entrance of the hall. The grade was then reversed, and the tunnel driven as far as the entrance of the machine hall. From this point, the entire face between the roof and the haunches was driven the full length of the machine hall. In order to obtain as neat faces as possible at the haunches, a line of holes 20 ft. deep, spaced 12 in. apart, was drilled. Then the drilling of the rock mass between the two lines of holes was carried out the full width of the machine hall to a depth of 18 ft. by means of drifters. The rock was blasted in herring-bone pattern using long-delay fuse caps to minimise overbreak.

The rock from these blasts was left in place over the whole area to support the wooden-arch formwork, 30 ft. long and set on rails, for pouring the concrete arch. When the whole length had been poured, mucking operations were carried out, and the remainder of the solid rock was mined in 15 ft. lifts down to grade. The muck below the level of the access tunnel which could not be hauled out was removed through the tailrace tunnel.

The tailrace cavern runs parallel to the machine hall some 40 ft. distant, and is 410 ft. long, 47 ft. wide,

and 75 ft. high. This chamber is approached by an access tunnel which branches from the main entrance tunnel. The area of the arch was driven the full length of the chamber and this was concreted with gunite and then grouted. Initially, the muck could be hauled out only through the north entrance; a ramp was thus developed along the length of the chamber, and the muck was hauled up it, through the north end, by truck, until the discharge tunnel for the tailrace was driven. The latter is 380 ft. long, 47 ft. wide and 65 ft. high and will carry the discharge to the open tailrace. The open part of the tailrace to the river is being dug in gravel by means of shovels, scrapers and bulldozers. A natural cofferdam is being left at the junction of the river, and will later be removed by draglines.

There are two erecting bays in the generator hall, one to the north of unit No. 1 at the entrance, and a smaller one to the south of unit No. 8. An emergency tunnel 8 ft. by 8 ft. has been driven at this end of the hall, leading to the switchyard, while between units 4 and 5, there is a tunnel 20 ft. wide and 11 ft. high, at right angles to the generator hall, crossing over the tailrace chamber and leading to the control building via an elevator. Eight tunnels, 8 ft. wide by 9½ ft., one opposite each machine, will carry the busbars upwards and out to the transformers in the switchyard.

The main bridge crane, which has two hooks each having a lifting capacity of 200 tons, is supported by concrete girders and columns poured against the rock walls of the machine hall. An auxiliary crane of 25 ton capacity is being used to great advantage in the construction work.

Ventilation will be provided by four blowers in a tunnel located at the north end of the tailrace chamber. They will circulate from 72,000 to 282,000 cu. ft. per min. into the cable passageway below the generator floor level for distribution to each unit. The air will be admitted directly to the machine hall for ventilation alone, or will be deflected through the generators when space heating is required. An interesting feature of the machine hall is that a false ceiling will be suspended from the arch, and this will serve as a return duct to the tailrace chamber, where a certain volume of the air will be discharged or recirculated. Blowers at the eight busbar tunnels will also discharge a minimum of 9,000 cu. ft. per min. and at the same time dissipate the heat generated by the busbars.

The eight valves for the penstocks were supplied by The English Electric Company of Canada, and it is interesting to note that these are the only valves in the system. The only other means of controlling the flow in the supply tunnel is the intake gate. These valves are termed "straight-flow" by the manufacturers, their characteristic feature being that there is a manually operated isolating seal in addition to the normal service seal, which allows servicing and replacing of the latter without dewatering the pen-

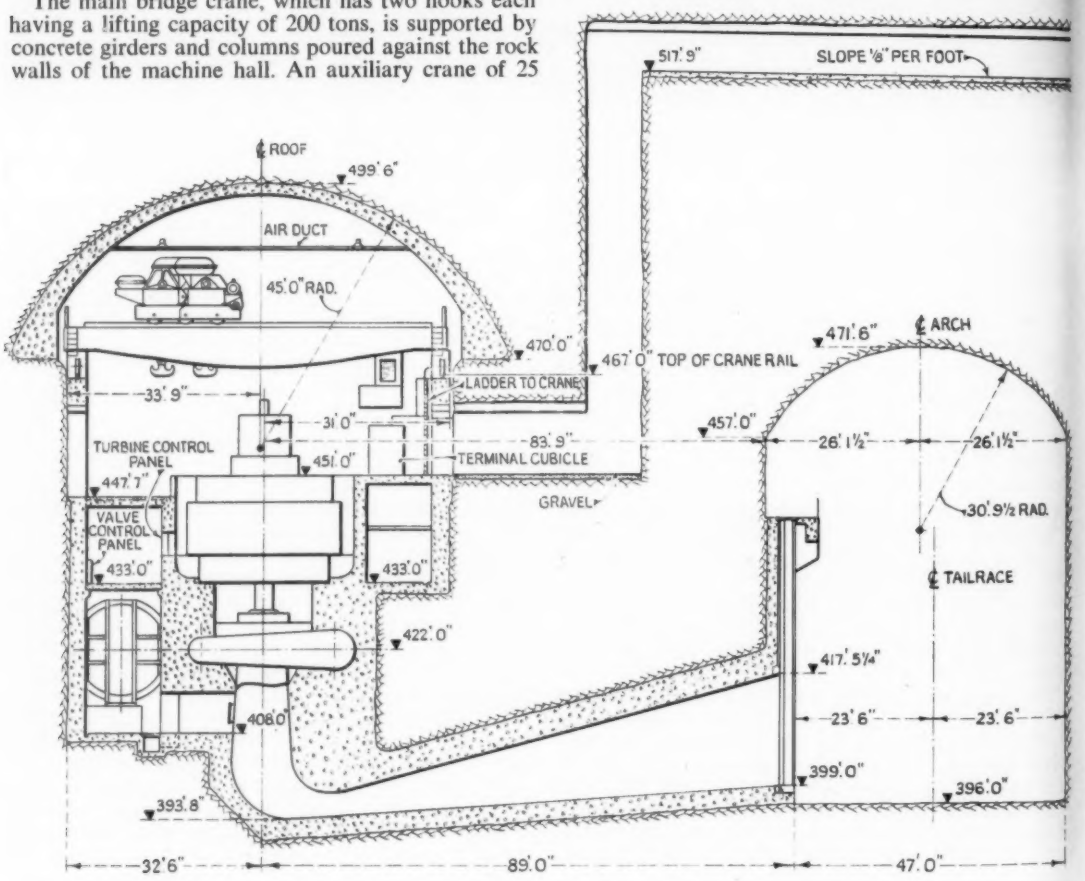


Fig. 16. Cross section of power house, showing general arrangement of units 1 to 4

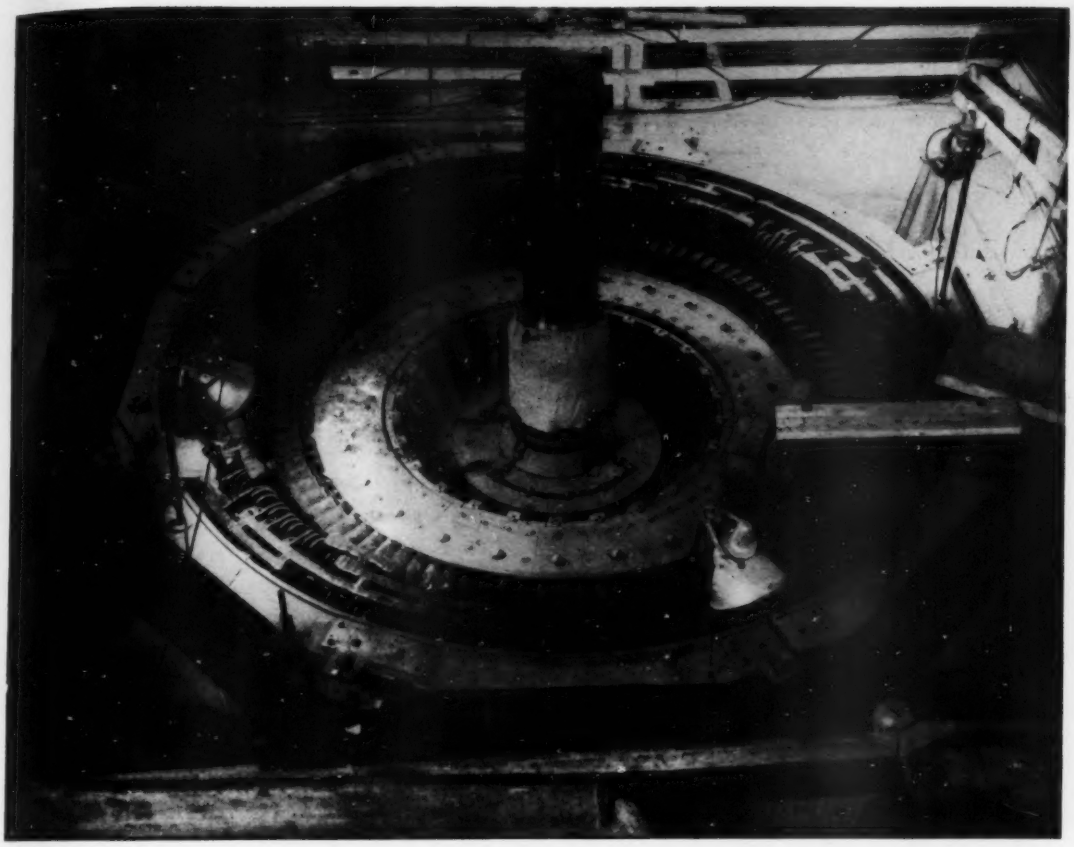


Fig. 17. One of the 120 MVA Metropolitan-Vickers generators in course of erection

Fig. 18. Service bay, with guide-vane assembly and turbine runner

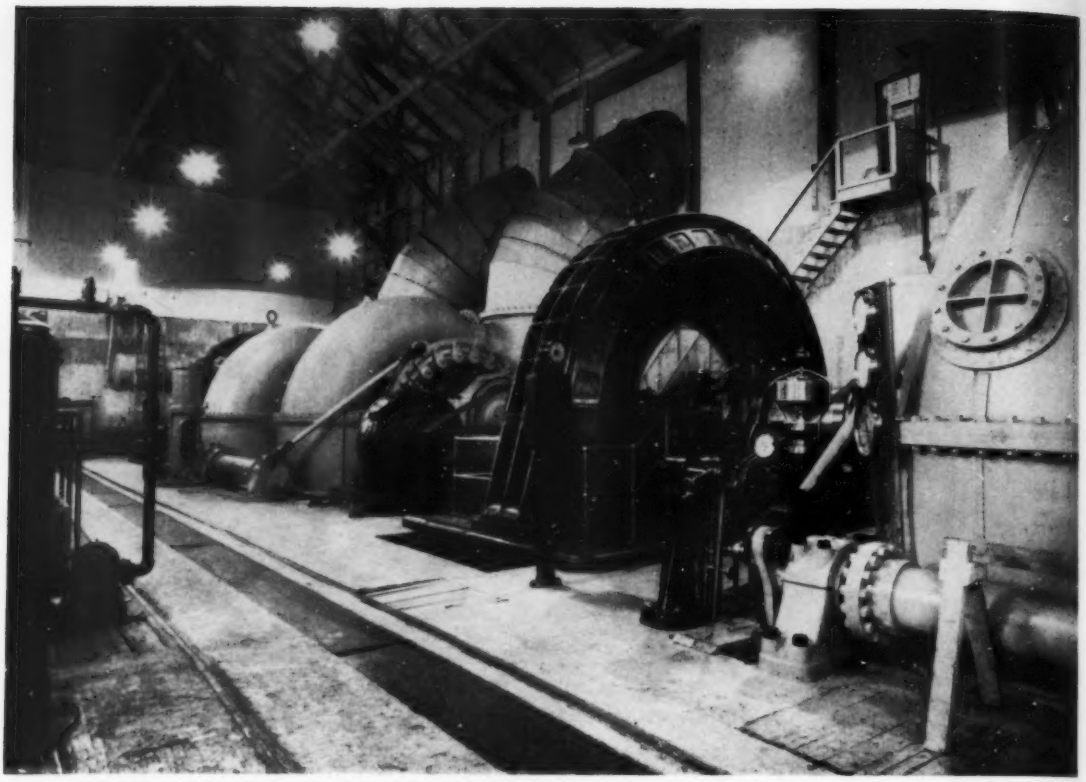


Fig. 19. A view in the temporary power house

stocks, and in this case, the whole tunnel. The valves have a diameter of 7 ft. 9 in., weigh some 160 tons, and are operated hydraulically by servomotor. The control panel for operating them is mounted in full view of the valves on the floor above turbine level.

The turbines for the first four machines were also supplied by The English Electric Company of Canada. They are of the Francis type and are capable of developing 175,000 h.p. at 277 r.p.m. under a static head of 875 ft. Their specific speed is 24. The runners are of cast stainless steel, designed with a labyrinth-type seal, and the scrollcases were fabricated. The first four units will be controlled by Woodward governors.

The other four machines will have hydraulic equipment supplied by Neyrpic Canada Ltd. The turbines, also of the Francis type, will have a rated output of 176,000 h.p. at 277 r.p.m. under a static head of 875 ft.; their specific speed will be 24·5. The governors for these units will also be supplied by Neyrpic Canada Ltd.

The Generators

The generators for the first four units were supplied by Metropolitan Vickers Electrical Co. Ltd., and are rated at 120,000 kVA at a power factor of 0·95, though they can be overloaded to 150,000 kVA. They generate at 13·8 kV, 60 cycles, and are designed for a temperature rise of 60°C. The cooling system is of the closed-circuit type, with eight water coolers fitted to the stator frame, the direction of air flow being controlled by ducting and baffles.

At the time of erecting, these machines have the largest output known in Western countries. The complete assembled rotor with laminated rim and 26 poles weighs 320 tons, not including the main exciter and thrust block. The thrust-bearing assembly is located above the upper guide bearing, and is cooled by an oil-to-water heat exchanger. Both upper and lower guide bearings are water cooled. The brakes may be operated hydraulically for lifting the rotor, or by compressed air for normal operation.

The stator bore is 207 in. and its depth is 105 in. There are 216 slots. The winding is lap, with two paths in parallel.

Mounted on the upper face of the thrust-block, at the level of the top of the spider shaft, is the rotor of the permanent-magnet generator which provides one source of supply to the motor driving a buck-roost exciter-generator set. The motor driving this set may alternatively be supplied from the station service supply, a selector switch for this purpose being mounted on the voltage-regulator cubicle which stands on the raised platform behind the units. The permanent-magnet generator is rated at 37 kVA and a power factor of 0·90, generated voltage being 580 V at 60 cycles. The armature of the main exciter is mounted on an extension shaft immediately above the permanent-magnet generator, and is rated at 437 kW at 350 V. The shunt field is designed to be self-exciting at normal speed and full load. A Woodward permanent-magnet generator controlling the governor, and incorporating overspeed tripping devices, forms the uppermost unit of the assembly.

The voltage regulator is a static device working in conjunction with the buck-boost exciter set which is located on the floor below the machine hall. It is capable of an extremely high rate of response and is continuously active with negligible dead band.

In the event of output voltage varying from normal, the error signal is fed to a three-phase voltage-setting auto-transformer, through a three-phase potential transformer, the primary of which is connected to the generator terminals. It is then rectified by a three-phase full-wave rectifier, and the resulting proportional d.c. voltage is fed into a Metrosil bridge. The auto-transformer is so set that at normal voltage the bridge is balanced and its output is zero. If the voltage rises above the rated value, the bridge output is in the bucking sense, and if it drops, the bridge output is in the boosting sense. This output is fed into a three-stage push-pull amplifier, and the amplified output is fed into the field of the first buck-boost exciter, then into the field of the second buck-boost exciter. As the armature of the latter is connected in series with the field of the main exciter, voltage control is maintained as the signal from the bridge is either in the buck or in the boost sense.

Generators for units 5 to 8 will be supplied by the Canadian General Electric Company. These will be rated at 120,000 kVA for a temperature rise of 60°C., and 138,000 kVA for a temperature rise of 80°C. Generated voltage will be at 13·8 kV, and the voltage regulators will be of the amplidyne type. It is expected that the fifth unit will be in service by the end of 1957, and the other three in 1958.

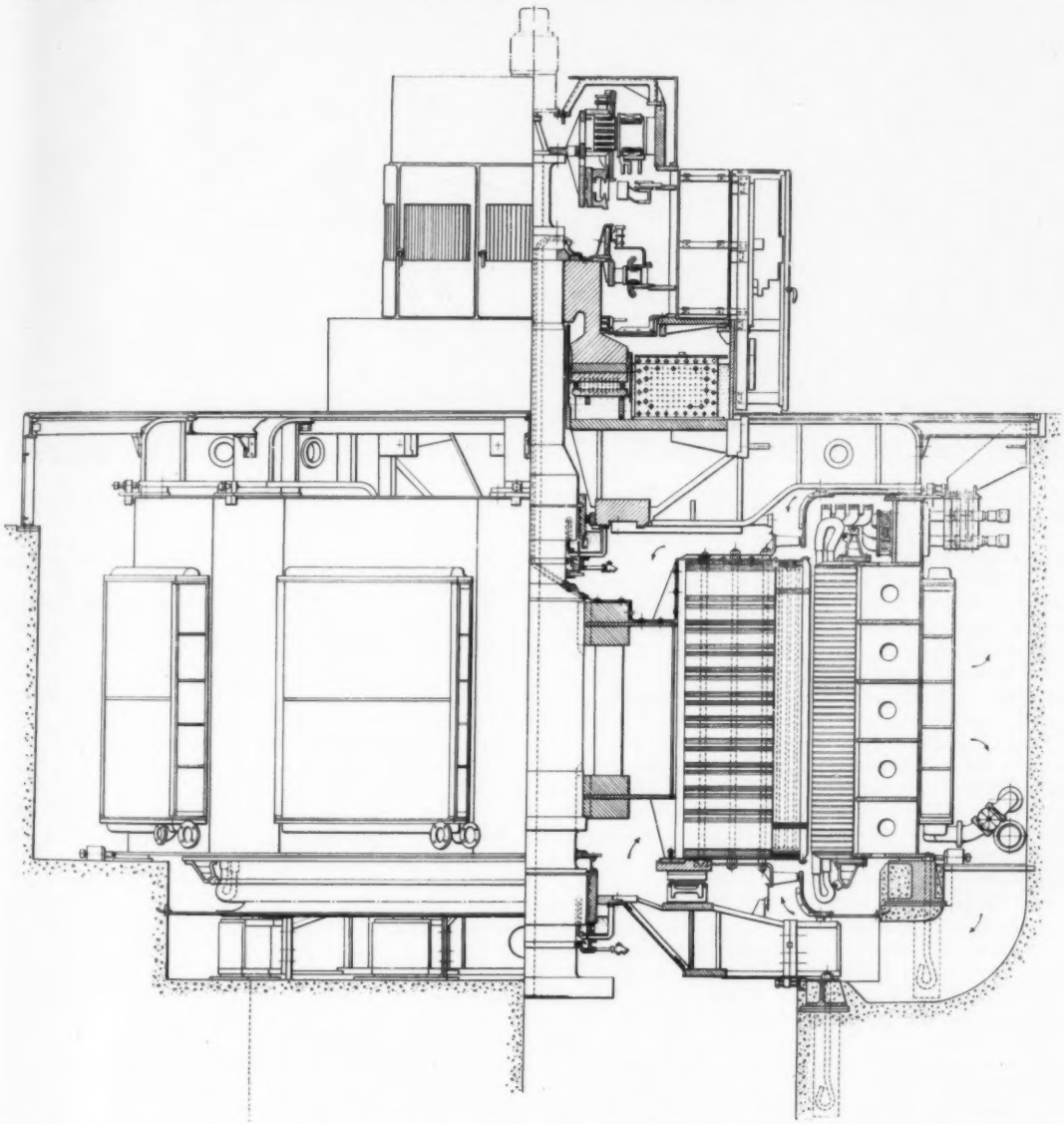


Fig. 20. Part-sectional elevation of a 120 MVA Metropolitan-Vickers generator. These are believed to be the largest waterwheel alternators in the world

Fig. 21. General view of Bersimis power house, looking south

The Control Building

Control cables from each set of four units are led away in five tiers of cable trays of expanded metal, bracketed to the wall of the cable passageway. They rise at the central portion of the passageway up to the floor above and into the tunnel access leading from the machine hall to the control room, continue in cable ducts on either side of this passage, and finally rise to the control room *via* the elevator shaft.

The control building is a three-storey structure erected in the open and standing between the mountain and the switching station. It is attractively furnished, air conditioned, and in addition to the engineers' and administrative offices, it will accommodate the municipal staff of the township of Labrieville.

In the basement is the 575 V distribution switchboard for station auxiliaries, though the transformers for this supply are in the power house on the elevated platform behind the machines, and may be coupled to any of the first four units. These transformers are of the dry type, rated at 1,500 kVA with 80°C. A.N.S., and are provided with automatic tap changers. Other equipment in the basement of the control building includes the transformers and distribution switchboard for the 208 V and 120 V lighting circuits, the battery room, selenium rectifier units for charging the battery, and the switchboard controlling the 125 V and 48 V d.c. supplies. Space has been provided for a 150 kVA diesel unit as a standby for the station auxiliaries.

The main control room is on the first floor, and the panel board is arranged in a wide modified semicircle. The whole is divided into sections, and instruments and controls for individual generators and transmission lines are mounted in alternate sections. In the centre of the panel are the instruments, controls and annunciator for the plant auxiliaries and townsite supplies; on the left are those for generators 1 to 4, and the two circuits of one transmission line; on the right are those for generators 5 to 8 and the two circuits of the other line. In the front and upper vertical part of the panel section for each generator are mounted the ammeter, frequency meter, kV meter, wattmeter and kVAr meter for that unit. Immediately under these is the annunciator panel for the same generator. The central portion of the panel slopes forward and carries the breaker controls and mimic bus, together with controls for the penstock valves, governors, and for the synchronising of each machine. Synchronising may be either automatic or manual, and there is a synchroscope on one section in each half of the panel board, one for each set of four units. On the lower vertical portion of each generator section of the panel are mounted the kWh, kVArh, and kV pen recorders for that unit.

The protective relays for each unit and transmis-

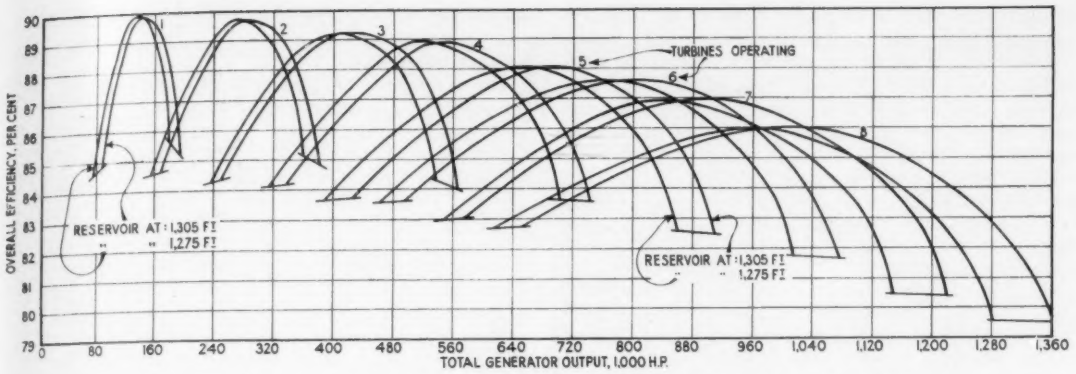


Fig. 22. Curves showing generator outputs and overall power-house efficiency

sion line are located at the back of the panel board, in the section corresponding to its position in the front of the panel. One section towards the centre in the left half of the board is used for meters indicating the total loads—megawatts and megavars—on all the units. For maintenance, there is an access way inside the control cubicle for the whole length of its arc, and is sufficiently high and wide for a man to walk through with ease.

A special desk for the operator is situated in the centre of the semicircle and carries a raised console which is provided with controls for voltage and load adjustment. The communication equipment, also operated from this console, comprises an internal telephone system, long-distance communication by carrier system on the H.T. lines, and a direct microwave link with Quebec and Montreal. Generally, the trend in design has been to eliminate control and operation as much as possible from the power house to the control room.

Transformers

The main leads, which have a capacity of 6,000 A at 13·8 kV, pass from the machines into a terminal cubicle located behind each generator on a raised platform. In this cubicle are the isolators, current and potential transformers, and earthing transformer. Isolated phase busbars consisting of conductors made up of two 8 in. aluminium channels supported inside an aluminium tubular enclosure, lead from the cubicles up to the eight shafts and tunnels previously described, where they continue as base bus out to the portal, and thence on isolated phase bus to the main transformer bank. Three single-phase current limiting reactors for the town and station service supply are located in the power house end of each tunnel, these being rated at 100 kVA, 209 A at 478 V for a 13·8 kV circuit. The busbars are protected from falling rock by a concrete roofing extending from the rock face of the mountain for some 50 ft. towards the transformers.

The 24 single-phase transformers were supplied by Canadian Westinghouse Company of Hamilton, Ontario. They are arranged in banks of three, in two groups of twelve, one group on each side of the control building. Contrary to the original decision to install three-phase transformers, banks of single-phase units were ordered as they could be furnished complete with delta bus at a cost substantially lower than a three-phase equipment. Also, the docking facilities at Forestville and the road to Labrieville placed limitations on the loads that could be transported. The possibility of building three-phase units on site was looked into, but was ruled out.

The rating of the transformers is normally 30 MVA, but is increased to 40 MVA when their cooling fans are in operation; they are designed for a temperature rise of 55°C. The low-voltage winding is arranged for delta connection of three transformers for operation on a nominal 13·8 kV system. The high-voltage side is connected in a star with a positively earthed neutral, it being designed for operation on a nominal three-phase, 301·4 kV system. The first two transformers are provided with a manual tap changer which can only be operated when the transformer is de-energised. These full capacity taps are provided for 167·5, 161, 154 and 148 kV. These were required initially to maintain full generator capacity at the low transmitting-end voltages required for the initial low transmission circuit loading. In two transformer banks a 26·55 kV tap on the high-voltage winding is connected to a 46 kV oil-filled bushing. This arrangement is for Bersimis No. 2 construction power supply and when this is being used, the transformer will step down from 301·4 to 46 kV as an auto-transformer with a bank capacity of 21,600 kVA, and the low-tension will be disconnected from the generating station bus. In all the transformers, the insulation of the high-voltage winding is graded from 1,050 kV basic impulse level, at the high-voltage end to 110 kV at the neutral end, while the basic insulation level of the low-voltage winding is 110 kV. The low-voltage windings of each set of transformers are delta connected to form a tertiary winding. Their O.N.S. rating is 75 per cent., and with the low temperatures that prevail in the winter months during the heavy-load periods, the cooling fans may never be called upon to operate. Under these conditions of favourable cooling, the nominal capacity of one bank will be 138,000 kVA, and their low value of reactance of 12 per cent. is a definite advantage.

Switching Station

The high-tension switching station equipment was supplied by Brown Boveri Company of Canada Ltd. Basically, the layout is a single bus and divided transfer bus type, so arranged that either or both of two generators may be used to energise either circuit of one double-circuit transmission line. At the same time, either or both of another pair of generators is available for the other double-circuit transmission line. A

sectionalising breaker is placed between the bus sections serving the two transmission lines respectively.

The circuit breakers are of the air-blast type; they are rated at 7,500 MVA and have a rupturing capacity of 1,000 A at 300 kV and 60 cycles. They will meet the required specification of being capable of interrupting 120 MVA of circuit charging kVA without restrike. The air is maintained at an operating pressure of 227 lb. per sq. in., and the control voltage for tripping is taken from the 125 V d.c. supply. The basic insulation level for all the switching station equipment is 1,300 kV.

The lightning arresters are rated at 242 kV, and a special feature is their large capacity to meet the specification values for switching surges on the long lines involved. For switching surges they have a capacity of 800 A for 2,200 micro-seconds, and for lightning surges they are capable of a discharge of 50,000 A.

Transmission Line

The problem of economically transmitting the energy from Bersimis over a distance of 350 miles across rugged and wooded terrain was an important factor in the decision as to whether the site should be developed. It must be remembered that although in the final stages approximately 3 million h.p. will be transmitted to the industrial centres, though in the coming decade only 1·2 million h.p. has to be catered for immediately. Economic studies were made on the possibility of using 230, 300, 345 or 380 kV for the transmission system. If the initial energy level of 1·2 million h.p. only had needed to be considered, a 230 kV system would have been the most economic, but for an ultimate figure of 3 million h.p. such a volt-

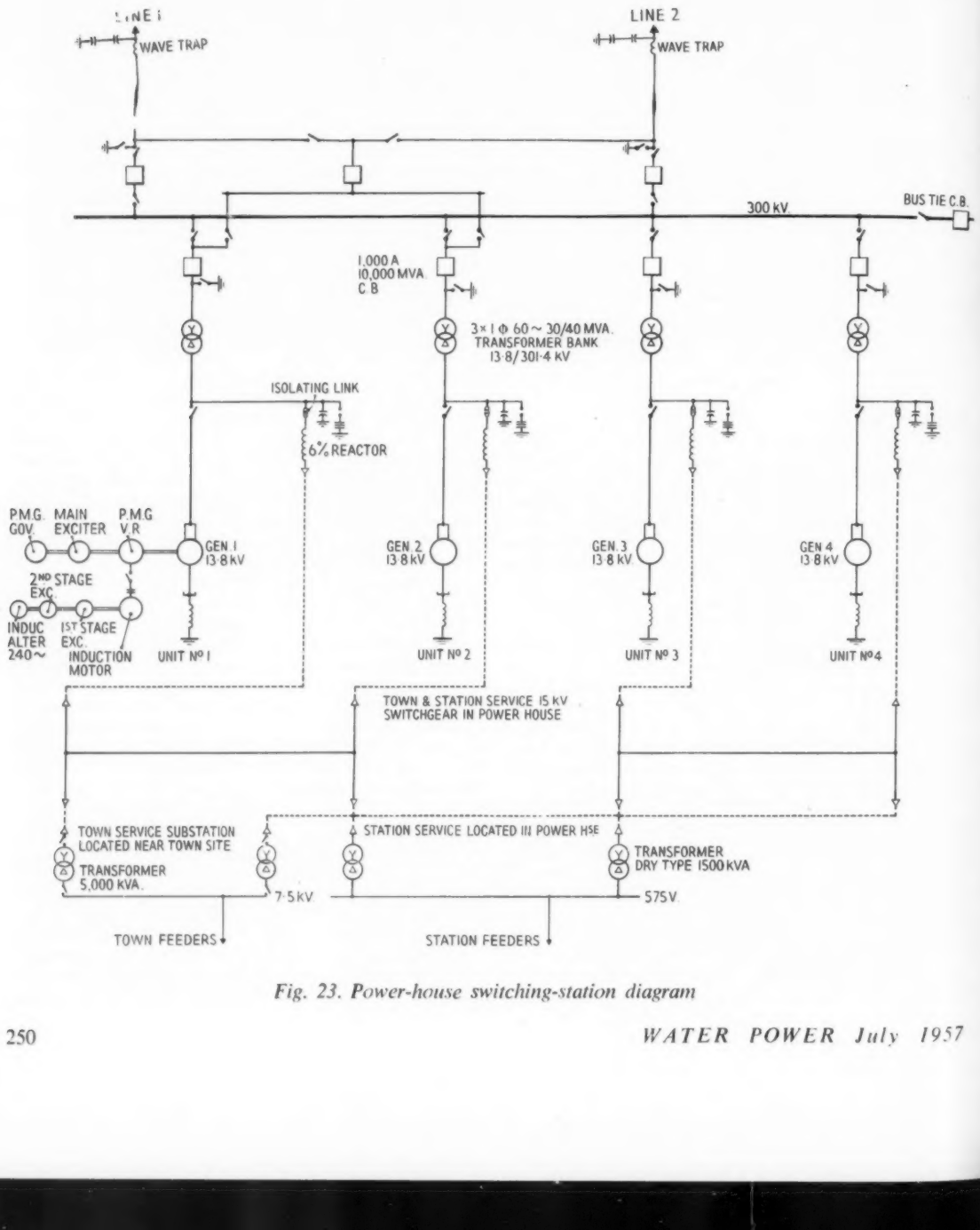


Fig. 23. Power-house switching-station diagram

age presented many problems. On the whole, 300 kV proved to be the most suitable considering the problems of corona, T.I.F., and other long-distance transmission difficulties, and that figure was consequently adopted. The final decision for the most economic and efficient transmission system was to have two separate lines, each having a double circuit at 300 kV.

One of the lines between Labrieville and the substation at Charlesbourg outside Quebec City has been completed. The main conductors are of A.C.S.R., having a cross-sectional area of 1,272,000 circular mils, except for a length of 4 miles from Charlesbourg, which is 1,590,000 circular mils. The cable consists of 54 strands of aluminium twisted over a steel cable of 19 strands.

The steel pylons carrying the two circuits have an average height of 138 ft. The ordinary suspension pylons weigh 14 tons, and the anchoring pylons 30 tons. The foundations are reinforced with lattice-type steel grille. Minimum distance between the conductors and pylons is 8 ft. 3 in. and clearance between the conductors is 30 ft. At the centre of the span the earthing cables are 38 ft. above the upper conductors, and minimum clearance from the ground itself is 35 ft.

Between Quebec City and the Saguenay River, the average span is 1,070 ft., while for the remainder of the distance to Labrieville, the span is 1,270 ft. The pylons carrying the lines across the Saguenay were built on elevated ground some 600 ft. high, thus assuring a clearance of 170 ft. above the river surface level. This span is 5,000 ft. long.

Two earthing cables of $\frac{7}{16}$ in. galvanised high-tensile steel are run above the conductors on each line. The towers themselves are earthed by wires at each foot, and buried to a depth of 12 ft. before filling the excavations. Counterpoises have not been installed where the measured resistance of the soil after filling a hole without a conductor is less than 20 ohms. If the resistance was between 20 ohms and 40 ohms, two cables were used; if above 40 ohms, four cables were used, and where necessary, a radial counterpoise was used to reduce the resistance to 20 ohms or less.

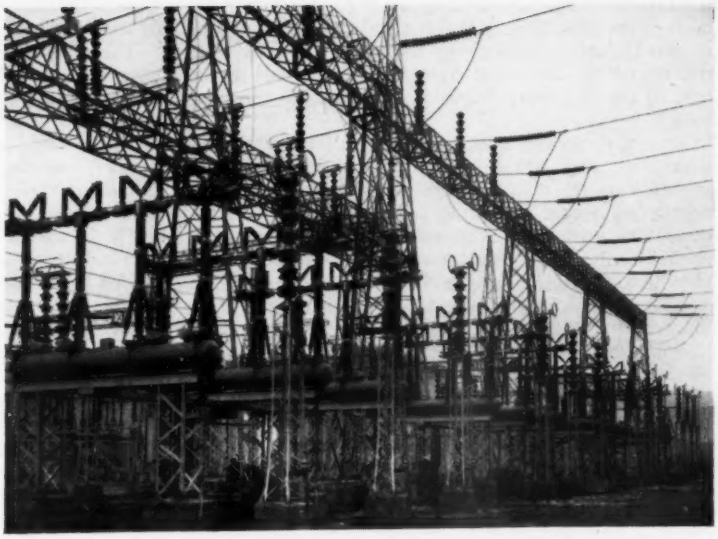


Fig. 24. Brown-Boveri of Canada 300 kV air circuit breakers

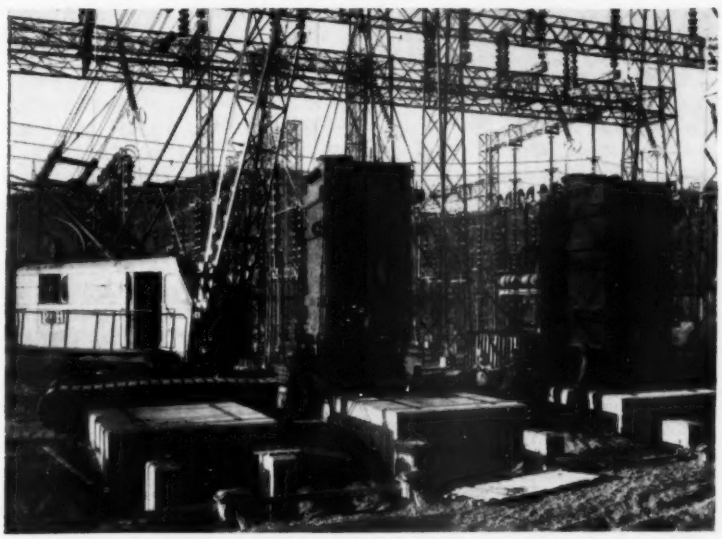


Fig. 25. Placing a Canadian Westinghouse 40 MVA transformer

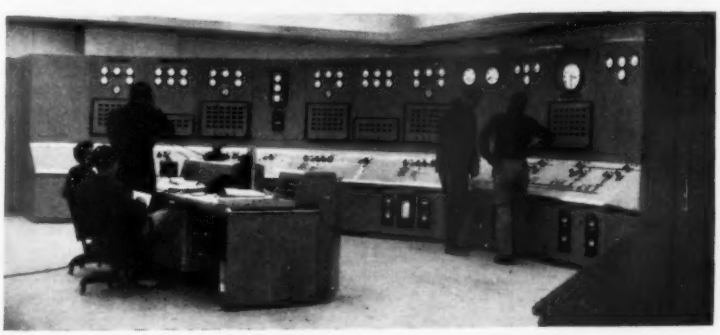


Fig. 26. Part of the control room

Transpositions are effected by two complete rotations of the phases, such that the corresponding phases of two circuits never occupy the same positions relative to one another. One transposition is made at the east of the Saguenay River and another on the west bank.

Arcing rings and horns are fitted to each chain of insulators, and vibration dampers at each point of suspension. At places where the cables are simply supported, single insulating chains made up of 21 insulators, each 5 in. deep and 10 in. in diameter are used. On the anchoring towers, and at those towers at which the line changes direction, the chains are double, consisting of insulators 5¾ in. deep and 10 in. diameter.

The transmission line follows the Labrieville-Forestville road for the first section, then runs along the North Shore coast of the St. Lawrence to Charlesbourg near Quebec. It is estimated that it will require 138,000 kVA to charge the line between Labrieville and Charlesbourg, *i.e.*, approximately the output of one machine. A 69 kV submarine cable to the Gaspe region has been laid and a 161 kV line to the Manicouagan peninsula will be erected to transmit power when the Bersimis No. 2 project is commissioned later in 1960.

The line is protected by carrier-circuit pilot-wire, and three-phase reclosing is used. The speed of automatic closing is 27 cycles, and 6 cycle simultaneous clearing at both ends can be achieved.

Construction Power

Before concluding, a brief account of the temporary plant supplying power for construction purposes and for the domestic requirements at Labrieville should be of interest, particularly as it constitutes the first hydro-electric development on the Bersimis River.

The power requirements for the project were necessarily large because of the dimensions of the major tunnel, and the necessity to excavate an underground power house. Diesel power was not economical for such a demand, nor was there time to erect a transmission line from the nearest source of power, the Outardes plant, which would have delayed the project by one year. The Commission therefore decided to intall a small plant at the Lac Cassé falls, just below the main dam, which proved to be an ideal site for this purpose.

The plant at St. Timothée on Lake St. Louis had recently been shut down permanently, and two of the four units there could readily be adapted to the construction requirements at Bersimis. The units are twin-turbine horizontal machines rated at 5,000 kVA, 2,300 V, and designed for normal operation under a head of 50 ft. Since a 90 ft. head was available at Lac Cassé, hydraulic efficiency was not of great importance here, but a trapped discharge to waste 40 ft. had to be arranged so that the units would not be subject to a head in excess of 50 ft. The two main problems encountered in this scheme were the variation in flow of the Bersimis, which was estimated between 1,600 and 70,000 cusecs, while the load on the two units would require a flow of 3,000 cusecs; and secondly, the problem of maintaining a constant supply when the main dam would cut off the natural flow. These problems were in part overcome by driving the diversion tunnel, and installing the regulating valve previously mentioned in connection with the construction of the dam.

There being no suitable roads at the time, the units were moved in during the winter of 1952 over tractor trails on skids, and a ferry service was maintained across the river as the ice on the Bersimis at that location was unreliable. The units were erected and ready for operation by July 1953, and the 44 kV transmission about 20 miles long, to all the construction sites and to Labrieville, was completed in October 1953. In the initial stages of construction, the plant was delivering up to about 10,000 kW.

The Consulting Engineers for the over-all Bersimis project were Messrs. H. G. Acres & Co., of Niagara Falls, Ontario, and the following contractors were assigned different parts of the construction work:

Cartier Construction Ltd., and Perini (Quebec) Ltd.
Excavation of tunnels and power house, also concrete lining of the tunnel.
Angus Robertson Ltd.
Construction of the dams.
Dufresne Engineering Ltd.
Preparation of concrete, construction of the power house, and part lining of the tunnel.
Komo Construction Ltd.
Construction of camps, permanent buildings, and public utilities at Labrieville, also constructing of the wharf at Forestville.
Anglo-Canadian Pulp & Paper Mills Ltd.
Construction of roads, supply of lumber, and transportation of materials to the sites.

The installation of the four Metropolitan-Vickers generators was undertaken by Canadian Westinghouse Co., Ltd., Field Installation Department, and the four English Electric turbines were installed by The Sterling Engineered Welderies Limited.

Acknowledgments

In preparing this article, much use has been made of Mr. F. Rouseau's paper "Bersimis-Lac Cassé Hydro-Electric Power Development," delivered at the annual Convention of the Engineering Institute of Canada in Montreal in May 1956. Grateful acknowledgments are due to Mr. J. O. Parker, co-ordinator of the project, Mr. H. Huggard, Chief Resident Engineer, and the engineering staff at Labrieville for liberal access to the drawing files and photographs. Some important facts have been obtained from the paper, "Aménagement Hydroélectrique de Bersimis-Lac Cassé," by Mr. Y. DeGuise, and also Mr. H. F. Abbott's paper, "Design Aspects of Bersimis-Lac Cassé Development," both of which were given at a joint meeting of the A.I.E.E. and the E.I.C. on January 12, 1955, in Montreal.

The author would also like to acknowledge with thanks the helpful information given by the following persons concerning the contribution of their companies to the project: Mr. F. Gariepy of Hydro-Québec; Mr. S. Revay of Dufresne Engineering; Mr. J. H. Richards of the Metropolitan-Vickers Electrical Co., Ltd.; Mr. J. Davis of the English Electric Co., Ltd.; Mr. W. D. Houser, Manager, Field Installations, and Mr. W. V. Ell, Erecting Superintendent, both of the Canadian Westinghouse Co.; and Mr. J. Jamieson of H. G. Acres & Co.

Finally, the author would like to express his indebtedness to Hydro-Québec for their collaboration and for their permission to prepare this article for WATER POWER.

The Double Surge-tank System

Dr. Charles Jaeger presents an original solution of the stability of double surge-tank systems—a problem that has hitherto been regarded as beyond general analysis

PART ONE

THE double surge-tank system to be analysed in this article consists of a system with one surge tank on the upstream side of a reaction turbine and another on the downstream side. The case of two surge tanks located on the same side of a turbine is not to be examined here; the method of approach would be the same and it is expected that the results would be similar.

Surges occurring in such tanks are usually calculated by graphical methods,[1,2]* but the general conditions for reaching surge stability have never been finally established. Since this system has first been described and analysed in 1943, it has been used for several large and very large surge tanks. The surge-tank system of Chute des Passes (Canada), expected to be the largest in the world, is of this type.† The present trend favouring underground power stations will cause many more tanks of the same type to be designed and built in the future. It becomes imperative to develop a complete theory of surge-tank systems, the more so as the opinion of specialists is divided on the practical conditions to be adopted for reaching stable oscillations. For many years the general equations for stability of surges in tank systems, established in 1943, were thought to have no general solution which could be properly discussed. It is the aim of this article to show such a general solution and to discuss it at full length.

The basic equations for oscillations in such a double surge-tank system, as given in the 1943 paper,[1] are:

$$\frac{L_1}{g}\frac{dW_1}{dt}+Z_1+P_1W_1^2=0 \qquad ...(1)$$

for the upstream tank and

$$\frac{L_2}{g}\frac{dW_2}{dt}-Z_2+P_2W_2^2=0 \qquad ...(2)$$

for the downstream tank. The two equations of continuity of masses are:

$$W_1f_1=F_1\frac{dZ_1}{dt}+Q \qquad ...(3)$$

$$Q=F_2\frac{dZ_2}{dt}+W_2f_2 \qquad ...(4)$$

where the surges Z_1 and Z_2 are positive in the upward direction. The meaning of the symbols W_1, W_2, L_1, L_2, f_1, f_2, F_1, F_2, and Q is given in Fig. 1.* The suffixes *1* and *2* refer respectively to the upstream and to the downstream tunnels and tanks, $P_1W_1^2$ and $P_2W_2^2$ are the friction and entry losses in the two tunnels.

In addition to these four equations, the equation for proper governing at constant output N requires that

$$N=\gamma\eta\, QH=\text{constant, or}$$

$$C=Q_0(H-P_1W_{10}^2-P_2W_{20}^2)=Q_0H_0=Q(H+Z_1-Z_2) \qquad ...(5)$$

where W_{10} and W_{20} are the velocities W_1 and W_2 for steady flow conditions, with $Q=Q_0$. In addition γ is the specific weight of the water and η an efficiency factor for turbines and electrical machinery.

In this equation (5) the net head H_0 is defined by

$$H_0=H-P_1W_{10}^2-P_2W_{20}^2$$

H being the gross head for $Q=0$.

It has been shown that the five equations (1) to (5) can be reduced to a system of two equations of the second order like:[1]

$$\frac{d^2s_1}{dt^2}+a_1\frac{ds_1}{dt}+b_1s_1=A_1\frac{ds_2}{dt}+B_1s_2 \qquad ...(6)$$

and

$$\frac{d^2s_2}{dt^2}+a_2\frac{ds_2}{dt}+b_2s_2=A_2\frac{ds_1}{dt}+B_2s_1 \qquad ...(7)$$

In these equations† s_1 and s_2 are the surges measured from the final steady flow level. If Z_1 and Z_2 are the

*The symbols used in this article are those introduced by Calame and Gaden and used by Escande and Houron and others dealing with the same problem.

†See equations (34) and (35) of the paper (1) by Ch. Jaeger, 1943 and equations (7) of the paper (5) by Escande and Houron, 1953.

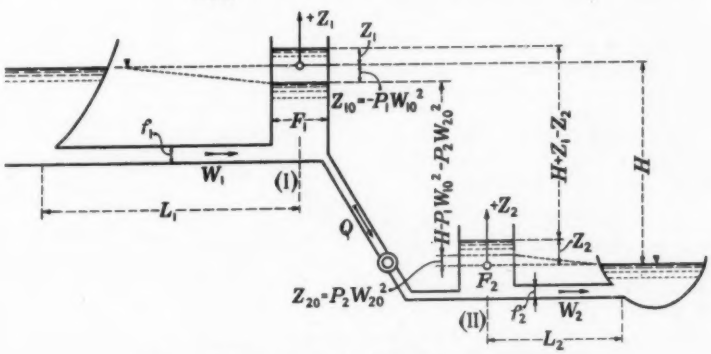


Fig. 1. Diagram of double surge-tank system

*The figures in brackets refer to the bibliography at the end of the paper.

†Designed by H. G. Acres, Consulting Engineers, for Aluminum Company of Canada.

surges measured from the steady reservoir level, and if $Z_{10}=-P_1W_{10}^2$ and $Z_{20}=-P_2W_{20}^2$ are the friction losses for steady flow conditions then

$$s_1=Z_1-Z_{10} \text{ and } s_2=Z_2-Z_{20} \quad \text{(Fig. 1)}$$

By linearising the equations (1) to (5), it can be arranged for the coefficients a_1, a_2, b_1, b_2, A_1, A_2, B_1 and B_2 to be constants. Equations (6) and (7) can then be reduced to a linear differential equation of the fourth order, which can be solved and discussed.

Two main problems have to be dealt with:

(a) The computation of the maximum positive and negative surges in both tanks, which is based on the non-linearised equations (6) and (7). The " graphical " computation is the only possible solution.

(b) The estimate of minimum design conditions, similar to the well-known rule of Thoma for stable governing conditions and the estimate of a convenient damping factor to be used for the surges. This investigation forcibly starts from the linearised, simplified equations.

In the 1943 paper several avenues were explored and all the possible methods of approach for solving the two problems pointed out and briefly discussed.

A direct calculation of surges using the extended graphical method of Schoklitsch is the obvious method of approach, extensive use of which was made in the 1943 paper.* It solves on one diagram both the problems mentioned under (a) and (b).†

The discussion of the general differential equation of the fourth order will give a positive answer to the second problem (b). This method already suggested in the 1943 paper was later on developed by Meyer[6] and by Escande and Houron[5], whereas the 1943 paper developed the so-called " time-average values " which give more rapidly an approximate estimate for the surge-tank areas to be used for preliminary designs.

In a joint paper by Balint, Flower and Frueh, on the surge tank of Kiewa No. 4 power station (Australia) the three methods (Schoklitsch, time-average values, and linearised equations) were used simultaneously and the results compared with a series of model tests. The results of all four methods were summarised in a diagram, which, because of its general interest, is reproduced here (Fig. 2).

In their paper on double surge tanks, Escande and Houron, pointing out the great number of free parameters involved, conclude that no general analysis of the stability problem is possible.

Additional research had therefore to be done, which comes under two main headings:

I. The systematic study of the general stability conditions.

II. The analysis of the required safety margin.

I. SYSTEMATIC STUDY OF THE GENERAL STABILITY CONDITIONS FOR DOUBLE SURGE-TANK SYSTEMS

Direct analysis. The analysis of the general conditions for surge stability is being taken up where Escande and Houron left it.[6]

Using the well known " relative values " introduced by Calame and Gaden, let:

$$T_1=2\pi\sqrt{\frac{L_1}{g}\frac{F_1}{f_1}}$$

$$T_2=2\pi\sqrt{\frac{L_2}{g}\frac{F_2}{f_2}}$$

$$Z_{*1}=W_{10}\sqrt{\frac{L_1}{g}\frac{f_1}{F_1}}=\frac{Q_0T_1}{F_1\,2\pi}$$

$$Z_{*2}=W_{20}\sqrt{\frac{L_2}{g}\frac{f_2}{F_1}}=\frac{Q_0T_2}{F_2\,2\pi}$$

be the basic periods and the maximum surges of the two independent systems *1* and *2* when friction is neglected.

For the surge tank *1*, on the upstream side of the turbines:

$$z_1=\frac{Z_1}{Z_{*1}},\quad x_1=\frac{s_1}{Z_{*1}},\quad w_1=\frac{W_1}{W_{10}},\quad dt_1=\frac{dt}{T_1},$$

$$h_{10}=\frac{H_0}{Z_{*1}},\quad p_{10}=\frac{PW_{10}^2}{Z_{*1}},\quad p_1=\frac{PW_1^2}{Z_{*1}}=p_{10}\,w_1^2$$

Similar " relative values " z_2, x_2, w_2, k_2, p_{20} and p_2

Fig. 2. Limiting stability curves for a typical double surge-tank system (Kiewa No. 4 power station, Australia)

*For the extended method of Schoklitsch, see Ch. Jaeger, "Engineering Fluid Mechanics, Glasgow," 1956, pp. 264-268.

†The use of an electrical analogous or of digital computors are modern alternatives to the graphical method.

will be defined for the downstream surge tank *2*.

Linearisation of the basic equations follows the pattern developed by Thoma for the simple surge tank: x_1 and x_2, dx_1/dt_1 and dx_2/dt_2 are assessed to be very small and products of higher order are being neglected.

When choosing a convenient definition for the relative time t common to both surge tanks, so that

$$\frac{dx_i}{dt_i}=\frac{dx_i}{dt}\cdot\frac{dt}{dt_i}=T_i\frac{dx_i}{dt}$$

the values of the constants a_1, b_1, A_1, B_1, a_2, b_2, A_2 and B_2 for the equations (6) and (7), (written in relative values) become, according to Escande and Houron:

$$\left.\begin{aligned} a_1&=-\frac{2\pi}{T_1}\left(\frac{1}{h_{10}}-2p_{10}\right), & b_1&=\frac{4\pi^2}{T_1^2}\left(1-\frac{2p_{10}}{h_{10}}\right)\\ a_2&=-\frac{2\pi}{T_2}\left(\frac{1}{h_{20}}-2p_{20}\right), & b_2&=\frac{4\pi^2}{T_2^2}\left(1-\frac{2p_{20}}{h_{20}}\right)\\ A_1&=-\frac{2\pi}{h_{10}}\frac{F_1}{F_2}\frac{T_2}{T_1^2}, & B_1&=-8\pi^2\frac{p_{10}}{h_{10}}\frac{F_1}{F_2}\frac{T_2}{T_1^3}\\ A_2&=-\frac{2\pi}{h_{20}}\frac{F_2}{F_1}\frac{T_1}{T_2^2}, & B_2&=-8\pi^2\frac{p_{20}}{h_{20}}\frac{F_2}{F_1}\frac{T_1}{T_2^3} \end{aligned}\right\}\quad\ldots(8)$$

These constants compare with the values*

$$2a=-2\pi\left(\frac{1}{h_0}-2p_0\right)\text{ and }b=4\pi^2\left(1-\frac{2p_0}{h_0}\right)$$

of the theory of simple surge tanks, based on the well-known equation

$$\frac{dx^2}{dt^2}+2a\frac{dx}{dt}+bx=0$$

The two equations (6) and (7) can be reduced to an equation of the fourth order, the associated equation being

$$p^4+\alpha_1 p^3+\alpha_2 p^2+\alpha_3 p+\alpha_4=0 \qquad \ldots(9)$$

where

$$\left.\begin{aligned} \alpha_1&=a_1+a_2\\ \alpha_2&=b_1+b_2+a_1a_2-A_1A_2\\ \alpha_3&=a_1b_2+b_1a_2-A_1B_2-B_1A_2\\ \alpha_4&=b_1b_2-B_1B_2 \end{aligned}\right\}\quad\ldots(9a)$$

The conditions of Routh and Hurwitz for stable or damped oscillations are:

$$\alpha_1>0,\ \alpha_2>0,\ \alpha_3>0,\ \alpha_4>0 \qquad \ldots(10)$$

and

$$\Gamma=\alpha_3^2-\alpha_1(\alpha_2\alpha_3-\alpha_1\alpha_4)<0 \qquad \ldots(10a)$$

Let:†

$$F_{Th_1}=\frac{1}{2g}\left(\frac{Q_0}{f_1}\right)^2\frac{L_1f_1}{H_0P_1W_{10}^2}$$

$$F_{Th_2}=\frac{1}{2g}\left(\frac{Q_0}{f_2}\right)^2\frac{L_2f_2}{H_0P_2W_{20}^2}$$

the so-called "Thoma" minimum areas for stable surges in tanks when considering two *independent* pressure systems characterised by the net head $H_0=H-P_1W_{10}^2-P_2W_{20}^2$, by a tunnel length L_1, and a tunnel cross-sectional area f_1 in one case, and by H_0, L_2 and f_2 in the other case.

*See Ch. Jaeger "Engineering Fluid Mechanics," p. 252.

†See Ch. Jaeger "Engineering Fluid Mechanics," 1956, pp. 237 and 244.

The condition (10) $\alpha_1>0$ yields then:

$$\frac{1}{F_1}+\frac{1}{F_2}<\frac{1}{F_{Th_1}}+\frac{1}{F_{Th_2}} \qquad \ldots(11)$$

The physical interpretation of this condition is obvious. Its mathematical implications can better be shown when writing

$$F_1=n_1F_{Th_1}\quad\text{and}\quad F_2=n_2F_{Th}$$

Equation (11) then becomes:

$$\frac{1}{n_1F_{Th_1}}+\frac{1}{n_2F_{Th_2}}<\frac{1}{F_{Th_1}}+\frac{1}{F_{Th_2}} \qquad \ldots(11a)$$

or when $\dfrac{F_{Th_1}}{F_{Th_2}}=\lambda$

$$n_2>\frac{n_1}{\lambda(n_1-1)+n_1}\ \text{ for } n_1\geq 1 \qquad \ldots(12)$$

Let us draw this curve

$$n_2=n_1/[\lambda(n_1-1)+n_1]\text{ or }n_1=n_2/[(n_2-1)/\lambda+n_2]$$

The condition $\alpha_1>0$ (see Fig. 3) corresponds to the area on the right and above the curve. For $\lambda=1$ the curve is symmetrical. The far more important condition $\Gamma<0$, in most cases the governing one, is now to be discussed.

The equations (8) and (9a) show that the condition $\Gamma<0$ (10a) written in relative values depends on the six parameters h_{10}, h_{20}, p_{10}, p_{20}, T_1 and T_2, which in turn depend implicitly on Z_{*1}, Z_{*2}, H_0, F_1 and F_2. Using absolute values, the problem has actually 10 independent variables. Escande[6] and others have expressed the opinion that the number of free parameters is too large for any general discussion of the conditions (10) and (10a) to be possible. It was suggested that the only practical approach was the direct use of numerical data corresponding to particular cases. This method has been illustrated by the 1943 paper and by the essays of Escande-Houron (1953) and Balint-Flower (1955).

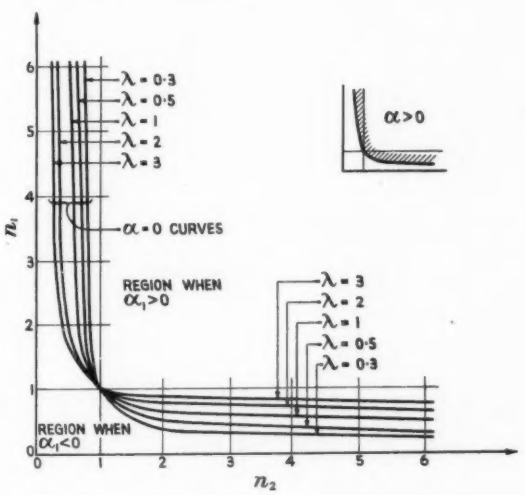


Fig. 3. Diagram (n_2, n_1) showing the region where $\alpha_1>0$ for various values of $\lambda=F_{Th_2}/F_{Th_1}$

A detailed general discussion is found to be practicable by choosing a new set of free parameters, all referred to the basic " Thoma areas," F_{Th_1} and F_{Th_2} for ideal surge tanks, calculated for the same head $H_0=H-P_1W_{10}^2-P_2W_{20}^2$. This method has already shown its usefulness, when discussing the damping of a single surge tank.† The basic idea is that F_{Th_1} and F_{Th_2} already contain the parameters L, F, PW_0^2 and H_0 implicitly and their introduction in the equations is bound to allow substantial simplification of the equations (6) and (7). In addition, F_{Th_1} and F_{Th_2} are known at the start of the problem and so are all the other parameters which will be used in the discussion, with the exception of n_1 and n_2, which are the couple of free variables to be determined later on, to satisfy the stability conditions.

Let, therefore:

$$Z_{*1}'=W_{10}\sqrt{\frac{L_1}{g}\frac{f_1}{F_{Th_1}}} \text{ and } Z_{*1}=W_{10}\sqrt{\frac{L_1}{g}\frac{f_1}{F_1}}=Z_{*1}'\sqrt{\frac{1}{n_1}}$$

$$Z_{*2}'=W_{20}\sqrt{\frac{L_2}{g}\frac{f_2}{F_{Th_2}}} \text{ and } Z_{*2}=W_{20}\sqrt{\frac{L_2}{g}\frac{f_2}{F_2}}=Z_{*2}'\sqrt{\frac{1}{n_2}}$$

$$T_1'=2\pi\sqrt{\frac{L_1}{g}\frac{F_{Th_1}}{f_1}} \text{ and } T_2'=2\pi\sqrt{\frac{L_2}{g}\frac{F_{Th_2}}{f_2}}$$

so that $$Z_{*1}'=\frac{Q_0T_1'}{2\pi F_{Th_1}} \text{ and } Z_{*2}'=\frac{Q_0T_2'}{2\pi F_{Th_2}}$$

and $$\overline{m}^*=\frac{T_2'}{T_1'}=\sqrt{\frac{L_2}{L_1}\frac{f_1}{f_2}\frac{F_{Th_2}}{F_{Th_1}}}=m^*\sqrt{\frac{n_1}{n_2}}$$

where $$m^*=\frac{T_2}{T_1}=\sqrt{\frac{L_2}{L_1}\frac{f_1}{f_2}\frac{F_2}{F_1}}$$

According to Escande and Houron:

$$h_{10}=\frac{H_0}{Z_{*1}},\quad h_{20}=\frac{H_0}{Z_{*2}},\quad p_{10}=\frac{P_1W_{10}^2}{Z_{*1}},\quad p_{20}=\frac{P_2W_{20}^2}{Z_{*2}}$$

†Ch. Jaeger, " Engineering Fluid Mechanics," 1956, p. 262–264.
†See Escande and Houron, equations (8)

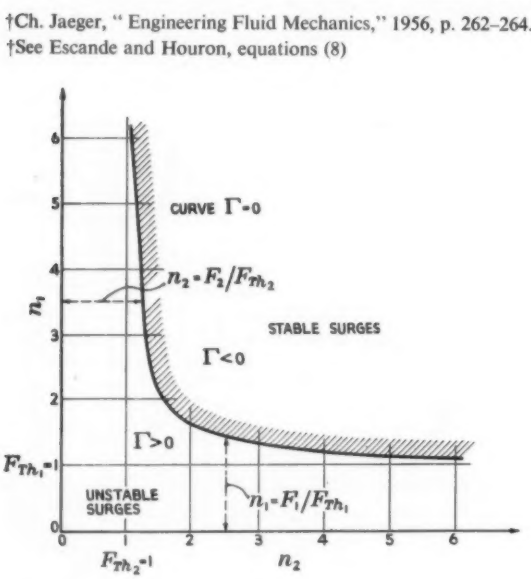


Fig. 4. Curve $\Gamma=0$ and definition of n_1 and n_2

Let the new relative values be:

$$h_{10}'=\frac{H_0}{Z_{*1}'},\quad h_{20}'=\frac{H_0}{Z_{*2}'},\quad p_{10}'=\frac{P_1W_{10}^2}{Z_{*1}'},\quad p_{20}'=\frac{P_2W_{20}^2}{Z_{*2}'}$$

so that:

$$h_{10}=\sqrt{n_1}\,h_{10}',\quad h_{20}=\sqrt{n_2}\,h_{20}'$$

$$p_{10}=\sqrt{n_1}\,p_{10}',\quad p_{20}=\sqrt{n_2}\,p_{20}'$$

Because of the definition of F_{Th_1} and F_{Th_2} it can be shown that for $n_1=n_2=1$, $a_1=0$ and $a_2=0$ and:

$$\frac{1}{h_{10}'}=2p_{10}' \quad \text{and} \quad \frac{1}{h_{20}'}=2p_{20}'$$

a very important relation which immediately simplifies all the constants of equations (6) and (7). These constants a_1, a_2, b_1, b_2, A_1, A_2, B_1 and B_2 have been calculated by Escande and Houron and expressed in relative values h_{10}, h_{20}, p_{10} and p_{20}. Let all these constants be transformed, using the new values as follows:†

$$\left.\begin{aligned} a_1&=\frac{2\pi}{T_1}\left(\frac{1}{h_{10}}-2p_{10}\right)=\frac{4\pi}{T_1}\,p_{10}'\left(\frac{1}{\sqrt{n_1}}-\sqrt{n_1}\right)\\ a_2&=\frac{2\pi}{T_2}\left(\frac{1}{h_{20}}-2p_{20}\right)=\frac{4\pi}{T_2}\,p_{20}'\left(\frac{1}{\sqrt{n_2}}-\sqrt{n_2}\right)\\ b_1&=\frac{4\pi^2}{T_1^2}\left(1-\frac{2p_{10}}{h_{10}}\right)=\frac{4\pi^2}{T_1^2}\left(1-(2p_{10}')^2\right)\\ b_2&=\frac{4\pi^2}{T_2^2}\left(1-\frac{2p_{20}}{h_{20}}\right)=\frac{4\pi^2}{T_2^2}\left(1-(2p_{20}')^2\right)\end{aligned}\right\} \quad ..(13)$$

$$\left.\begin{aligned} A_1&=-\frac{2\pi}{h_{10}}\frac{F_1}{F_2}\frac{T_2}{T_1^2},\quad B_1=-8\pi^2\frac{p_{10}}{h_{20}}\frac{F_1}{F_2}\frac{T_2}{T_1^3}\\ A_2&=-\frac{2\pi}{h_{20}}\frac{F_2}{F_1}\frac{T_2}{T_2^2},\quad B_2=-8\pi^2\frac{p_{20}}{h_{20}}\frac{F_2}{F_1}\frac{T_2}{T_1^3}\end{aligned}\right\} \quad ...(13a)$$

It follows from equations (9) and (9a),† with $m^*=\overline{m}^*\sqrt{(n_2/n_1)}$ and writing $1/n_1=X$:

$$\alpha_1=-2\pi\left[\frac{1}{T_1}\left(\frac{1}{h_{10}}-2p_{10}\right)+\frac{1}{T_2}\left(\frac{1}{h_{20}}-2p_{20}\right)\right]$$

or:

$$\alpha_1=-\frac{4\pi}{T_2}\left[X\,\overline{m}^*p_{10}'\sqrt{n_2}-\sqrt{n_2}(\overline{m}^*\,p_{10}'+p_{20}')+\frac{p_{20}'}{\sqrt{n_2}}\right] \quad ...(14a)$$

$$\alpha_2=4\pi^2\left(\frac{1}{T_1^2}\left(1-\frac{2p_{10}}{h_{10}}\right)+\frac{1}{T_2^2}\left(1-\frac{2p_{20}}{h_{20}}\right)+\right.$$
$$\left.+\frac{2}{T_1T_2}\left[2p_{10}p_{20}-\left(\frac{p_{10}}{h_{20}}+\frac{p_{20}}{h_{10}}\right)\right]\right)$$

or:

$$\alpha_2=\frac{4\pi^2}{T_2}\{Xn_2[\overline{m}^{*2}(1-(2p_{10}')^2)-4\overline{m}^*\,p_{10}'p_{20}']+$$
$$+(1-(2p_{20}')^2)+4\overline{m}^*\,p_{10}'p_{20}'(n_2-1\} \quad ...(14b)$$

$$\alpha_3=-\frac{8\pi^3}{T_1T_2}\left[\frac{1}{T_1}\left(\frac{1}{h_{20}}-2p_{20}+\frac{4p_{10}p_{20}}{h_{10}}\right)+\right.$$
$$\left.+\frac{1}{T_2}\left(\frac{1}{h_{10}}-2p_{10}+\frac{4p_{10}p_{20}}{h_{20}}\right)\right]$$

$$\alpha_3=-\frac{8\pi^3}{T_2^3}\overline{m}^*\{X[2\overline{m}^*p_{20}'][\sqrt{n_2}+$$
$$+n_2\sqrt{n_2}((2p_{10}')^2-1)]+X[2p_{10}'\sqrt{n_2}]+$$

†See also Escande and Houron, equations (12) and (12').

$$+2p_{10}'\sqrt{n_2}[(2p_{20}')^2-1]\} \quad ...(14c)$$

$$\alpha_4=\frac{16\pi^4}{T_1^2T_2^2}\left[1-2\left(\frac{p_{10}}{h_{10}}+\frac{p_{20}}{h_{20}}\right)\right]$$

or:

$$\alpha_4=\frac{16\pi^4}{T_2^4}\,\overline{m}^{*2}\times n_2[1-(2p_{10}')^2-(2p_{20}')^2] \quad ...(14d)$$

When calculating the equation $\Gamma=0$, it appears that T_2 is everywhere at the power minus six and $\Gamma=0$ can be written:

$$T_2^6\,\Gamma=T_2^6[\alpha_3^2-\alpha_1(\alpha_2\alpha_3-\alpha_1\alpha_4)]\lessgtr 0$$

The positive quantity T_2^6 can be eliminated. All the four constants α_1, α_2, α_3 and α_4 now contain explicitly the values n_1 and n_2 (which were previously implicitly contained in the values a_1, a_2, b_1 ...) and the final equation $\Gamma=0$ becomes now an equation of the third degree in $X=1/n_1$, with n_2 as main variable parameter, the other three remaining free parameters being $\overline{m}^*$, p_{10}' and p_{20}'.

The whole problem can now be readily discussed and the resulting curves $n_1=n_1(n_2, \overline{m}^*, p_{10}', p_{20}')$ can all be drawn on the same diagram, as shown on Fig. 4. The formulae (10), (10a) and (14) solve the problem.

In this diagram Fig. 4, F_{Th_1} and F_{Th_2} are each taken as units, to that $n_2=F_2/F_{Th_2}$ is the abscissa and $n_1=F_1/F_{Th_1}=1/X$ is the ordinate. All the curves drawn for the three parameters $\overline{m}^*$, p_{10}' and p_{20}' are asymptotic to $n_1=1$ and $n_2=1$. The condition $\Gamma<0$ is fulfilled in the area to the right of and above the curve $\Gamma=0$. The curves (12) corresponding to the condition $\alpha_1>0$ can be drawn on the same diagram, but then curves have now to be drawn for the actual values of $\lambda=F_{Th_2}/F_{Th_1}$, taken as a new parameter. It will be found that the condition $\Gamma<0$ is, with few possible exceptions, the more important one.

General Discussion of the Condition $\Gamma<0$.

The results of the detailed calculations are shown on Fig. 5a, 5b and 5c where curves are traced for $\overline{m}^*=0{\cdot}2$, $\overline{m}^*=1$, and $\overline{m}^*=5$. For p_{10}' and p_{20}' the values 0·1 and 0·3 have been adopted. In practical cases, the real value of the friction losses will be found to correspond to a relative value near $p_0'=0{\cdot}1$ and 0·3 is an upper limit which probably will be reached rarely. The curves on which the discussion is based are shown in Table I, and they cover probably a wide range of practical cases.

The case $\overline{m}^*=0{\cdot}2$ usually corresponds to a short tailrace tunnel whereas the case $\overline{m}^*=5$ will usually characterise a system with a long tailrace tunnel as compared to the upstream headrace tunnel. In addition, the values obtained by Escande and Houron, those by Balint and Flower for Kiewa (Australia) and those for Chute des Passes (Canada) have been included on the diagrams. Escande analysed a system characterised by

TABLE I. VALUES OF THE PARAMETERS

Curve	$\overline{m}^*$	p_{10}'	p_{20}'
1	0·2	0·1	0·1
2		0·3	0·3
3	1	0·1	0·1
4		0·3	0·3
5	5	0·1	0·1
6		0·3	0·3

$$\begin{array}{llll} L_1= & 1000m & L_2= & 700m \\ f_1= & 10m^2 & f_2= & 10m^2 \\ F_1= & 40{\cdot}8m^2 & F_2= & 79{\cdot}3m^2 \\ Z_{*1}= & 10m & Z_{*2}= & 6m \end{array}$$

He keeps $P_{20}=0{\cdot}36m$ constant and varies P_{10} the friction loss on the upstream side from $1m$ to $0{\cdot}50m$. Assuming $F_1=F_{Th_1}$ and $F_2=F_{Th_2}$ he calculates the heads H_{OL_1} and H_{OL_2} for which the two tanks would just be stable, supposing they were working alone. Finally H_{OL} is the head for which the two-tank system is just stable. It is easy to check that

$$n_1=H_{OL}/H_{OL_1} \qquad n_2=H_{OL}/H_{OL_2}$$

$$Z_{*1}'=Z_{*1}\sqrt{n_1} \qquad Z_{*2}'=Z_{*2}\sqrt{n_2}$$

$$m^*=\sqrt{\frac{L_2}{L_1}\frac{f_1}{f_2}\frac{F_2}{F_1}}=1{\cdot}166 \text{ and } \overline{m}^*=m^*\sqrt{\frac{n_1}{n_2}}$$

$$p_{10}'=\frac{p_{10}}{\sqrt{n_1}} \qquad p_{20}'=\frac{p_{20}}{\sqrt{n_2}}$$

Table II summarises the additional calculations which were made starting from Escande's values.

The values n_1 and n_2 are:

for case:	1	2	3	4	5
n_1 =	1·235	1·126	0·995	0·97	0·98
n_2 =	1·235	1·24	1·195	1·388	1·96

These points are shown on diagram Fig. 5b.

The curve corresponding to Kiewa surge-tank

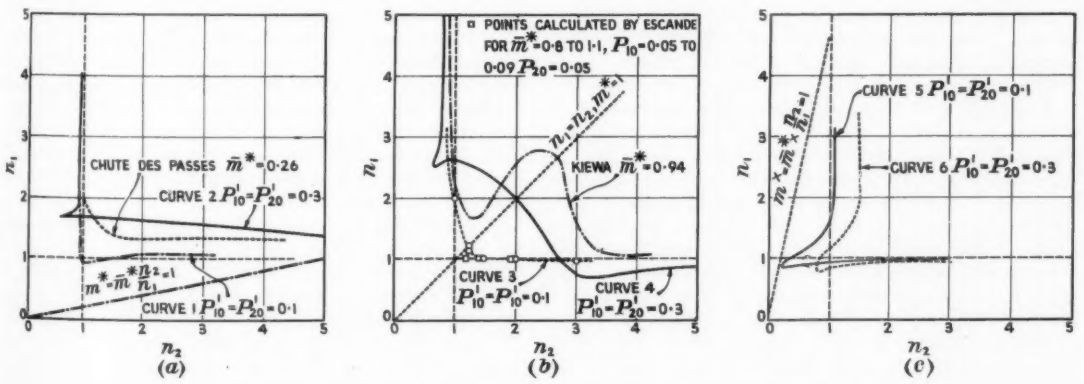


Fig. 5. Diagrams $n_1=n_1(n_2)$ for $\overline{m}^*=0{\cdot}2$ (Fig. 5a), 1 (Fig. 5b) and 5 (Fig. 5c)

TABLE II. ADDITIONAL PARAMETERS

Case	P_{10}	P_{20}	H_{0L}	H_{0L1}	$\sqrt{n_1}$	p_{10}'	H_{0L2}	$\sqrt{n_2}$	p_{20}'	n_1/n_2	$\overline{m}^*$
1	1	0·36	61·8	50	1·11	0·09	50	1·11	0·054	1	1·166
2	0·91	0·36	62	55	1·06	0·086	50	1·113	0·0539	0·91	1·11
3	0·833	0·36	59·7	60	0·997	0·083	50	1·093	0·055	0·835	1·063
4	0·7	0·36	69·5	71·4	0·985	0·071	50	1·178	0·0503	0·7	0·975
5	0·5	0·36	98	103	0·99	0·05	50	1·4	0·0429	0·5	0·826

system is taken from Balint and Flower's paper (see Fig. 2). The characteristic data of these tanks are:

$L_1 = 15250$ ft. $\quad L_2 = 7330$ ft.
$f_1 = 285$ sq. ft. $\quad f_2 = 340$ sq. ft.
$P_{10} = 50{\cdot}5$ ft. $\quad P_{20} = 9$ ft.
$F_{Th_1} = 75$ sq. ft. $\quad F_{Th_2} = 165$ sq. ft.

These values lead to

$Z_{*1}' = 235$ ft. $\quad Z_{*2}' = 101$ ft.
$p_{10}' = 0{\cdot}215 \quad p_{20}' = 0{\cdot}089$
and $\overline{m}^* = 0{\cdot}94$

The values obtained by Flower are also entered on Fig. 5b.

The Chute des Passes tank system (project) is characterised by the following values:

$F_{Th_1} = 2800$ sq. ft. $= 300m^2 \quad F_{Th_2} = 7000$ sq. ft. $= 750m^2$
$\overline{m}^* = T_2'/T_1' = 0.255$
$Z_{*1}' = 58{\cdot}2m \quad Z_{*2}' = 37{\cdot}2m$
$P_{10} = 11m \quad P_{20} = 5{\cdot}67m$
$p_{10}' = 0{\cdot}189 \quad p_{20}' = 0{\cdot}152$

The curve found for the Chutes Des Passes tank by using direct the equations (12) and (12′) by Escande and Houron (page 651 of their paper) has been reproduced in relative values $n_1 = n_1(n_2)$ on Fig. 5a for comparison with other curves.

Some valuable information will be obtained by comparing Fig. 5a, 5b and 5c where more general curves have been drawn.

For $\overline{m}^* = 1$ ($T_2' = T_1'$), Fig. 5b, there is an obvious danger of resonance, and in particular on curve 4 ($p_{10}' = p_{20}' = 0{\cdot}3$), where n_1 should be greater than 2 ($n_1 > 2$) when $n_2 < 2$ such requiring large surge-tank areas. This curve more or less confirms the curve calculated for Kiewa.

The conclusion is that, where $\overline{m}^* = 1$ at least one of the surge tanks might have to be far larger than F_{Th}; with possibly $n = 2$ or even $n = 3$, so the other tank can be kept smaller. It is a matter of local conditions to decide which tank has to be the one with the large area. For reasons of design and construction it often is the downstream tank.

It will be noted that the curve 4, corresponding to $\overline{m}^* = 1$ and $p_{10}' = p_{20}' = 0{\cdot}3$ yields far larger n values than curve 3 ($p_{10}' = p_{20}' = 0{\cdot}1$), but on the other hand, high friction losses reduce even more substantially the basic F_{Th} area. It can be said that high friction losses do stabilise the surges (as in the case of ordinary single tanks).

Conditions are much easier for $\overline{m}^* = 0{\cdot}2$ or $\overline{m}^* = 5$ ($T_1' \neq T_2'$). The case $\overline{m}^* = 0{\cdot}2$ usually corresponds to a short tailrace ($T_2' < T_1'$); case $\overline{m}^* = 5$ to a long tailrace. Here also, the importance of the friction losses can be recognised on the curves and also the advantage of choosing one of the values n_1 or n_2 substantially larger than one ($n_1 > 1$ or $n_2 > 1$) in order to keep the other value n_2 or n_1 down.

Checking of condition $\alpha_1 > 0$ or

$$\frac{1}{F_1} + \frac{1}{F_2} < \frac{1}{F_{Th_1}} + \frac{1}{F_{Th_2}}$$

will usually lead to no special limitation with the exception of certain parts of curve *1* or curves *5* or *6*.

This general analysis is possible only because relative values were introduced based on F_{Th_1} and F_{Th_2} taken as units to which all the other values are referred. The physical meaning of F_{Th_1} and F_{Th_2}, n_1 and n_2 is obvious. As F_{Th_1} and F_{Th_2} already implicitly contain a great number of variables like L, f, PW_0^2, and H the number of free parameters is being reduced and the problem can be solved.

(To be continued)

Drainage Pumps for Kariba Power Station

Rhodes, Brydon & Youatt Limited have received an order from Boving & Co. Limited, London, for the supply of seven vertical motor-driven drainage pumps for installation in the power station in Kariba Gorge. Three drainage sumps are to be provided and these will be equipped with a total of four R. B. & Y. 3 in. three-stage vertical Mopumps. The pumps will run at 1,450 r.p.m. and will deliver 200 g.p.m. against a maximum head of 130 ft. or a minimum of 83 ft., each being fitted with a 17½ h.p. motor.

To facilitate periodic inspection of the turbine casings and draft tubes an elaborate layout of piping and valves has been arranged embedded in the foundations of the power station. To this pipe system will be attached two 9 in. V.H. vertical Mopumps. Each of these will be capable of de-watering the turbine casings and draft tubes at a rate of 2,000 g.p.m. against a maximum head of about 80 ft. This head will of course vary during operation as the level in the turbine casing is pumped down and special attention has been paid to the pump characteristics in order to limit the power absorbed when operating in the low-head conditions.

These pumps are of the vertical single-stage centrifugal type with the suction flange coupled directly on to the pipe system which interconnects the five turbine casings. They are driven by 90 h.p. motors running at 1,450 r.p.m.

A larger pump of similar design is being provided for de-watering the tail-race tunnel. This will be a 14 in. V.H. vertical Mopump capable of delivering 4,000 g.p.m. against a maximum head of 85 ft. at 950 r.p.m. and will be driven by a 170 h.p. motor. This pump is of the dry sump type and will be attached to the pipe system embedded in the foundations of the power station.

A considerable amount of thought has been given to this drainage and de-watering system and close collaboration has been necessary between the pump manufacturers and Boving & Co. Limited, in order that a final decision of pipe sizes could be reached well in advance of the actual due date for the pumps. Since much if not all of the piping has to be laid at the same time as the power station foundations, this preliminary work was very necessary.

Book Reviews

Die konstruktive Durchbildung von Wehranlagen mit mechanischem Antrieb (Constructional Design of mechanically driven Spillway Gates) by F. W. Peilert. Published by VEB Verlag Technik, Berlin NW 7, Unter den Linden 12, 5.2 in. by 8 in., 249 pp., 142 ff. Price in Germany DM.32·00.

This work, the first to reach us from Eastern Germany, deals especially with the various problems involved in the constructional design of spillway gates. Owing to the popularity achieved in Germany by rolling gates, it is not surprising that no less than 115 pages of the volume are devoted to this pattern of gate and its various types: conventional, submerged, and adjustable by means of flaps. All the other traditional designs are dealt with in separate chapters and there is also a special chapter for unconventional types. The characteristic features of each design are first described and discussed, and the various elements of calculation, stresses, etc . . . are reviewed in detail. A comparative survey of three of the main types, roller, vertical gate and taintor gate, appears in section 2.41, p. 207, and there are paragraphs on the oscillations occuring in gates in instances of submerged flow and free overfall. The work concludes with chapters on erection work, operating regulations and stoplogs and other emergency gates. Intended as a reference book for designers specialising in this class of structures, this neat little volume will also be welcomed by students, and it should offer no insuperable difficulty to the English reader commanding a fair knowledge of German.

Recommendations for the Classification of Materials for the Insulation of Electrical Machinery and Apparatus in Relation to their Thermal Stability in Service (I.E.C. Publication No. 85). International Electrotechnical Commission, 1 rue de Varembé, Geneva. Price Sw. Fr. 5.

The classification of insulating materials contained in this publication is a revision and extension of the classification previously given in the 1930 and 1935 editions of I.E.C. Publication 34, "Rules for Electrical Machinery," to cover the introduction of new materials and manufacturing processes. The number of classes has been increased from four to seven, and a maximum temperature is associated with each class, which if respected will ensure an economic life for the insulation in a wide range of apparatus. The classification given in this publication does not deal with temperature-rises. An appendix contains lists of insulating materials which as the result of tests or experience may be considered appropriate to each class.

Power Production. By Hans Thirring, Ph.D.Vienna. English edition published by George G. Harrap & Co. Ltd., 182 High Holborn, London, W.C.1. 399 pp. 96 ff. Price 25s. net.

The author of this book, who is a Professor of Physics at the University of Vienna, has set himself the task of covering the whole field of power production, giving special attention to future needs and possibilities. All aspects of power production are considered and the author's approach is such that this work can be read with equal interest by the secondary-school boy who is seeking to grasp fundamental principles or the industrial magnate who is seeking to broaden his views on the general economics of power production. There is, of course, little of direct interest to the hydro-electric engineer, but the position that water power assumes in the world today and its trend towards future expansion are reasonably summarised, although there are some rather strange opinions on the relation between hydro and thermal plants for meeting peak loads. Other chapters deal with steam and steam engines, internal-combustion engines, heat pumps, generation of electricity, coal, petroleum, natural gases, fossil fuel reserves, solar energy, atomic energy, nuclear reactors and thermo-nuclear reactions.

Professor Thirring writes lucidly and is always interesting, and his broad, technical knowledge is pleasantly leavened with philosophical reflections which are usually informative, occasionally challenging and sometimes whimsical.

Le Poste de Bétonnage (Concreting Plant), by O. Rodé and A. P. Ducret, published by Société de Propagande et de Diffusion des Techniques du Bâtiment, 33, Avenue Kléber, Paris XVI, 8½ in. by 10½ in., 200 pp., 135 ff. Price in France, cloth-bound, Fr. 4,000.

By means of tables, diagrams and graphs, this work places at the disposal of concrete technologists, both in the office and in the field, the maximum of practical information they need when working out the organisation of a concreting plant and planning its layout with a view to improving efficiency and production and making supervision easier, whatever the extent of the contract on hand. The first part of the book deals with fundamentals: labour and the human factor, and materials and equipment. The latter chapter is divided into two sub-sections: (a) mixers and the various types of drives involved; (b) supply, stocking, batching and other machinery. The second part, which fills two-thirds of the volume, deals in its first section with 23 different types of concreting plants varying in output from 15 to 150 cu. m. per day of 8 hours; there is, for each type, a diagram showing the set-up of the plant and a costing form, with blank pages and forms inserted for types occuring in practice other than those instanced. The final section is devoted to various questions of costing and production, and is based on conditions obtaining in France. This book provides an excellent guide-book to the concrete specialist when having to decide about the most economic layout of a concreting plant under given conditions and circumstances.

Hot-Line Maintenance Work. A particularly interesting addition to the "Blue-White Series" published by the Swedish State Power Board is No. 17 in the series, devoted to hot-line maintenance work. A country as dependent as Sweden on long-distance electrical transmission needs continuity of service above everything, and this objective is greatly served by special techniques of carrying out maintenance work on live lines. This booklet describes, with admirable illustrations, the methods employed by the Board and the meticulous care that is taken in the training of teams and in the supervision and testing of equipment.

The Durance Project

This article describes some investigations into the ground-water hydrology of the Lower Durance area, and is followed by an Appendix on the recent state of constructional progress at Serre Ponçon

By Peter O. Wolf, B.Sc.(Eng.), A.M.I.C.E., A.M.I.W.E.

PART FOUR

THAT extensive percolation studies were carried out during the design stage of an earth dam, 120 m. (400 ft.) high and resting on 110 m. (360 ft.) of alluvium of high permeability, is hardly surprising, although the work done on this problem proved to be remarkably fertile in new ideas*.

In the case of the Lower Durance project, however, extensive additional ground-water studies have been undertaken: some of them were doubtless necessary in order to reassure the designers of this great scheme that all was well, but it appears that a great deal of additional work was undertaken with the aim of providing evidence, acceptable to the lay public, of the benefits of the project in every direction. What might be called the "public-relations" aspect of scientific investigation is unusual, but there is no doubt about the value of patient experiments which provide clear evidence of the good intentions of Electricité de France towards the local agricultural community, and of the respect which this great national electricity undertaking wishes to show for the feelings of the—perhaps in some cases rather unscientific—local individual.

The great value of agricultural production in the valley of the Lower Durance, and its dependence on irrigation, were referred to in Part One†. The agricultural community was aware of the existence and the value of a considerable body of ground water under their land, and Electricité de France considered it their duty to prove that the proposed interference with the natural flow of the river (by smoothing out the larger variations in discharge by the construction of large reservoirs, and by the diversion of 250 cu. m. per sec. of water from the Lower Durance to the power canal) would not affect the ground-water body to the detriment of agriculture.

Ground water in the vicinity of the Lower Durance is used in several ways. Farmers living at a distance from centres of domestic water supply draw their drinking water from their own wells or, in a few cases, from springs formed where the water table rises to the surface. In certain belts of land, the mean depth of the water table makes it possible to carry out intensive agriculture without artificial irrigation; in other areas, pumping irrigation water from shallow wells is more economical than conducting it from the river in long canals. A special feature is the practice—explained later—of draining otherwise swampy ground upstream of a "defile" and using the drainage water for irrigation of fields downstream. A reduction in the ground-water flow and a lowering of the water table would grossly interfere with all these well-established practices.

The Valley of the Lower Durance

The Lower Durance project extends from Cadarache, below the mouth of the Verdon, to Mallemort—a distance of approximately 50 km. downstream. About

* G. Schneebeli, in "The Serre Ponçon Dam on the Durance: Study of the Percolation" (in French), *La Houille Blanche*, Special Issue A/1955, describes tests on a three-dimensional scale model and on an electrical analogue, and refers to problems of capillarity and of unsteady seepage flow with a free water table.

† WATER POWER, Vol. 9, No. 4, April 1957, p. 148.

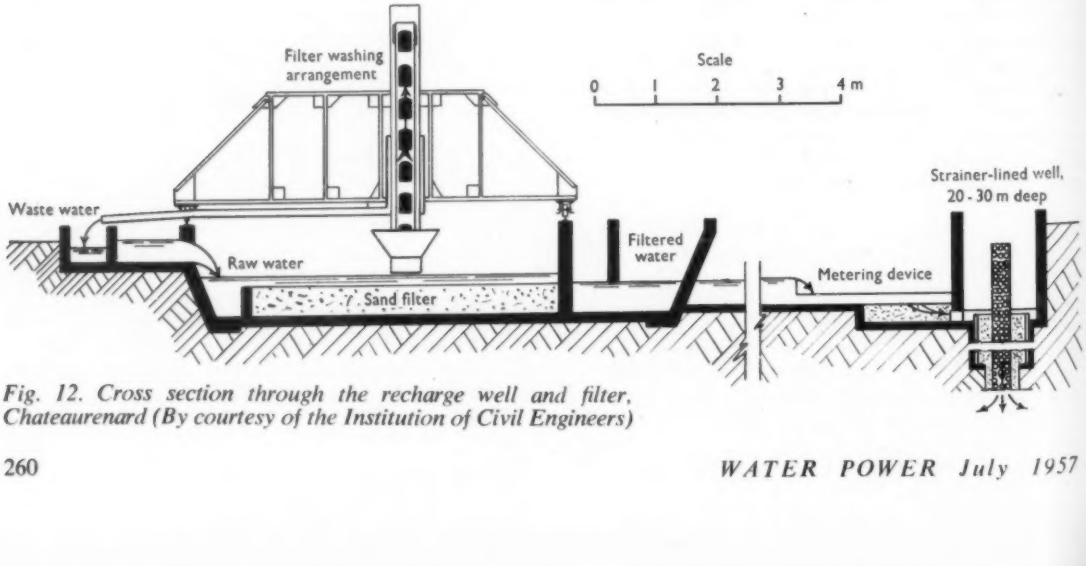


Fig. 12. Cross section through the recharge well and filter, Chateaurenard (By courtesy of the Institution of Civil Engineers)

Fig. 13. A view of the recharge well and filter at Chateaurenard

10 km. west of the proposed Mallemort power station, the power canal is to turn south, through the Pass of Lamanon, leaving the natural catchment of the Durance and heading for Salon and Lake Berre‡. The valley is confined between the Luberon mountains to the north of Mallemort and, on the left bank, the Cotes range east of Lamanon and the Alpilles to the west. These hilly ranges thrust out spurs towards the river, so forming four defiles, at Mirabeau near Cadarache, at Cadenet 15 km. upstream of Mallemort, at Orgon 10 km. downstream of Mallemort, and at Noves at a further distance of 20 km. downstream and just upstream of Chateaurenard; and four basins, the largest of which is that of Saint-Andiol between Orgon and Noves.

In each basin, alluvial deposits, mainly of sand and gravel, provide a plane surface of uniform slope roughly equal to that of the river, namely 3/1,000. The mean thickness of the alluvium is 10 m., with a maximum of approximately 40 m. The permeability of the alluvium was measured at more than a thousand points, usually by pumping water at a steady rate into recharge wells. A representative value of the horizontal permeabilities so determined is 4 mm. per sec. The permeability of the bed-rock is comparatively negligible. The Durance flows through the successive basins in a river channel varying in width from 400 to 1,000 m. (with occasional widths of nearly 1,500 m.).

During the past decade both Electricité de France and an independent ground-water specialist commissioned by the local agricultural interests have carried out an extensive and thorough programme of investigation. Over 1,500 observation wells and bore-holes have been sunk, and the number of observations taken by last summer was approaching a million. Numerous contour maps of water tables observed at various seasons and with various river flows and rainfalls have been prepared. Simultaneously, rainfall, river and canal-flow records have been kept on a large scale. Since it was found that the influence of these factors on the ground-water flow could not only be large but rapid, many continuously recording instruments have been installed, including 130 well-level recorders. As a result, it has been possible to prepare charts showing the influence on the position of the water table of rainfall and of the water levels in the various water courses.

The broad conclusions of these studies are as follows*:

The water table in the areas surrounding the alluvial basins is invariably above the water table in the alluvium, and ground-water flow is in the direction of the river.

Except near the upstream and downstream ends of each basin, the longitudinal slope (2/1,000) of the water table is less than the gradient of the river (3/1,000). At the upstream end of the basin, for a short distance, the water table is actually below low water in the river. At the downstream end the water table is considerably higher than the river level. The longitudinal slope of the water table through each topographical and geological defile is very steep, and there is a considerable ground-water flow from one basin to the next, as well as into the river: the latter movement is greatly assisted by the agricultural drain-

‡ See map in Part Three. WATER POWER, Vol. 9, No. 6, June 1957, p. 221.

* A. Decelle, M. Guelton and R. Muller-Feuga, "Ground Water in the Lower Durance Valley and the Agricultural and Power Development in that Area" (in French), Second Congr. Int. Comm. Irrig. Drain., Algiers, April 1954, Quest. 4, *Report* 13, p. 4.225.

age system installed in the downstream area of each basin.

Floods in the Durance, though violent, are of short duration and separated by long periods of low discharge. The water table, as far as it is influenced by the Durance, corresponds to steady conditions at low river levels.

The rates of flow into and out of the river differ considerably. At the upstream end of the Saint-Andiol basin, for example, the water table is 10 m. below the surface and 3 m. below river level. Near the river the water table was found to be very steep—falling 2·5 m. in a distance of 3 m.—and calculations show a total discharge from the river to the ground water of 0·65 cu. m. per sec. (23 cusecs) over a length of 3 km. at a river discharge of 300 cu. m. per sec. The explanation of this low figure lies probably in the fact that the Durance carries, per cu. m., approximately 1 kg. of silt and clay particles in suspension which form a sealing deposit of mud where there is a tendency for water to seep into the bed. This deposit is presumably disturbed by heavy flood discharges during which the flow to the ground water is greatly increased.

The flow of ground water into the river is continuous at the downstream end of each basin and exceeds the loss from the river. Careful gauging of all surface-water discharges showed the net contribution of the ground water to the flow in the Lower Durance, in the dry summer of 1949, to have been between 10 and 20 cu. m. per sec.

The effect of rainfall on the water table has been found to be generally small. Of the mean annual rain of the order of 600 mm. (24 in.) a large proportion falls at high intensity, with long intervals of drought, and surface run-off greatly exceeds infiltration. Only at the foot of the hills has rainfall been observed to cause a large rise in the water table.

Irrigation from the artificial canal system is provided at the rate of an equivalent depth of approximately 2 m. during the growing season which coincides with the driest six months of the year. Not only is this amount a multiple of the total annual rainfall, but by its regularity its effect on the ground water is further increased. Irrigation is, therefore, considered to be one of the chief sources of ground water.

The Crau

This is the plain stretching south and west from the Alpilles and the Pass of Lamanon to the Mediterranean and to the Rhône. Its area is approximately 500 sq. km., and it slopes at a uniform rate from elevation 115 m. at the Pass of Lamanon in the north-east down to sea level. Geologically it consists of the alluvial gravels left by the Durance in its former southward course during the Early Quaternary. Agricultural development, and indeed civilised settlement, are barely four centuries old, for Craponne's canal, the first canal providing the area with water from the Durance, bears the date 15th April, 1559.

The reason for including the Crau in the ground-water investigation lay in a hypothesis, put forward in 1930, according to which the ground water in the Mallemort basin of the Durance valley found an overflow in the Pass of Lamanon and thereby provided the Crau basin with a valuable "underground river." If such a "river" existed, any lowering of the water table in the Mallemort basin would undoubtedly reduce its discharge.

The French Government were interested in this problem for reasons of municipal water supply and, with Electricité de France and the agricultural interests, provided a third independent research team. Again the investigations were extensive and thorough†: geological borings, geophysical soundings, and permeability tests, which showed the floor of the Pass to consist of virtually impermeable strata, were supplemented by a dye test and a hydrological study of the Crau basin. Four years ago dye was injected into the ground water just north of the Pass of Lamanon, and observations since then have shown this body of dye to be in slow, but steady, movement towards the Durance.

The hydrological study has shown the Crau to be an independent ground-water basin, fed by irrigation supplies and rainfall, and losing 5 to 10 cu. m. per sec. to the sea. The mean annual rainfall is of the order of 400 mm. (16 in.) which, without losses, would represent 6 cu. m. per sec. Irrigation canals bring Durance water through the Pass of Lamanon at the rate of 35 cu. m. per sec. for roughly 10 months in the year. Observations in 300 wells constructed for the purpose have shown that the water table in the north and east of the basin is influenced by the rainfall, and over the remainder of the basin depends on artificial irrigation which—by the development of the great Durance reservoirs—is to be fully safeguarded in future.

Design and Construction of the Lower Durance Works in Relation to Ground Water

The power canal starts at Cadarache, a few km. upstream of the Mirabeau defile, at an elevation of 256 m. It follows much flatter slopes than the Durance so that at the power stations, where the tail-race levels have been chosen to be approximately equal to the Durance levels opposite each station, there are useful heads available for power generation. This choice of tail-race levels has the double advantage of fitting in with ground-water conditions and of enabling each station to come into operation before the next station downstream is completed, by discharging the used water into a temporary tail race leading back to the Durance. The head-race canals will be fully lined, but the tail-race canals will have pervious sides in order to avoid the build-up of small differential heads.

The barrage at Cadarache is sited where the valley is wide and the depth of the alluvium great. The width occupied by the works is only a small fraction of the total width of the alluvial aquifer, and the ground-water flow to the north of the barrage will, therefore, be little affected. The effect of the barrage will be to raise the upstream level by up to 9 m. and this increased head will cause approximately the same amount of ground-water flow under the works as had existed in the past: the cut-off driven into the alluvium below the barrage does not reach to the impermeable bed-rock, and is only long enough to provide the requisite flat hydraulic gradient. After a short period of normal operation, the bed of the pond at Cadarache should become covered with a muddy sealing layer virtually separating the surface and ground-water flows.

† A. Decelle, M. Guelton and R. Muller-Feuga, "Ground Water in the Crau Basin and the Diversion of the Lower Durance—Importance of Irrigation" (in French), Second Congr. Int. Comm. Irrig. Drain., Algiers, April 1954, Quest. 4, *Report* 12, p. 4.217.

Fig. 14. View along the centreline of Serre Ponçon dam from the observation platform on the right bank, showing the Serre de Monge, with the entrance to the main spillways in the foreground, the top layer of grouted alluvium under the watertight core being removed

Generally the water level in the power canal will be above the water table, and there is, therefore, no danger of any loss of ground water to it. Where a large proportion of the aquifer is affected by the construction of the canal, special works, such as transverse siphons, are to be constructed to maintain a free ground-water discharge.

Artificial Recharge

In the past, the flow in the Lower Durance, during periods of drought, fell to so low a value that less than 50 cu. m. per sec. would be available for the irrigation and water-supply canals. Low canal flows, in their turn, caused a reduction in flow to the ground water which will not be experienced in future when the great reservoirs will ensure a drought discharge of well over 100 cu. m. per sec. In spite of this improvement, Electricité de France has been mindful of the reverse change which will result from the storage of floods in the reservoirs: in the past, the net infiltration from the river to the ground water, in times of high water (4 to 8 weeks per year), was estimated to amount to 1 or 2 cu. m. per sec., and an effort has been made to ensure such supplies even without raising the river levels, by artificial recharge.

Pilot experiments were started, in 1953, at Plan d'Orgon in the Saint-Andiol basin, and at Seignone near Avignon. As a result, it has been possible to carry out a successful full-scale recharge programme, during the past year, at Chateaurenard and also at Peyrolles (in the basin downstream of the Mirabeau defile).

The pilot tests showed artificial recharge to be both feasible and free from objectionable secondary effects: at Plan d'Orgon, a supply of 1 cu. m. per sec. after one month had raised the water table in the whole of the Saint-Andiol basin from its mean annual minimum to its mean annual maximum level‡. The Seignone site is only 800 m. upstream of the ground-water intake to the Avignon water-supply pumping station: protracted tests involving numerous bacteriological samples from various bore-holes have shown that raw river water is purified within a seepage distance of 50 to 80 m.

The test at Chateaurenard is the most important one of all. The town is situated near the upstream end of the lowest basin which extends down to the junction with the Rhône. The whole basin is agriculturally of great value, and it has been served for many years by a highly developed network of irrigation canals in the north-eastern part, and by an extensive drainage system in the west and south, the origins of the latter going back to the eleventh century. The alluvium in the basin is up to 30 m. thick, and the permeability decreases from approximately 8 mm. per sec. in the east to 1 mm. per sec. or less in the west where the aquifer is covered by a clayey blanket. The range of

‡ A. Decelle and R. Muller-Feuga, "General Notes on the Alluvial Water Table in the Lower Durance Valley" (in French), *La Houille Blanche*, Special Issue B/1956, p. 52.

pressure variations of 20 to 30 cm., under this blanket at the south-western end, is associated with a natural variation in the water table upstream of Chateaurenard of 1 m. or more.

The radius of influence of the recharge works is 2 to 3 km., and the natural water table is on average 4 m. below ground level at the upstream end of this zone, and 2 m. at the downstream end. The depth of the ground-water body is roughly 20 m., the permeability of the order of 8 mm. per sec. and the effective porosity of the aquifer 6 to 12%. After several trials, an arrangement with five recharge wells was adopted, and five such installations are used to deliver 1·1 cu. m. per sec. (nearly 40 cusecs) to the ground water (see Figs. 12 and 13). Since the raw water is drawn from irrigation canals fed by the Durance, it has to pass through a filter bed before flowing into the well. Each well, filled with gravel to a diameter of 56 cm., reaches down to the impervious bed-rock*.

A test run in January and February, 1956, when the water table would have been at its lowest point on the annual cycle, raised the water table close to its annual peak: after 29 days' recharge the water table had been raised more than 60 cm. over an area of 17 sq. km., more than 40 cm. over 24 sq. km., and more than 20 cm. over 33 sq. km. This and subsequent tests proved that recharge wells are a sensitive means of water-table control and that the injection of more than 1 cu. m. per sec. is both easy and cheap.

Ground-water problems have been encountered in connection with hydro-electric developments in the United States, on the Continent of Europe, and in Scotland†, but the thoroughness and ingenuity of the French engineers faced with their special problems in the Durance valley could hardly have been surpassed. The goodwill of the inhabitants of an area to be developed is of incalculable assistance, and it is to be hoped that in this respect—as in the scientific one—Electricité de France will be entirely successful.

Acknowledgments

Thanks are due to Mons. R. Giguet, of Electricité de France, and to his colleagues, for supplying information and for making possible a friendly exchange of views; also to the following societies for permission to include some of their illustrations in these articles: The Institution of Civil Engineers, Société des Ingénieurs Civils de France (British Section), International Association of Scientific Hydrology.

Appendix

Notes by two postgraduate students of hydro-power engineering at Imperial College, A. A. Kemp, B.E., A.M.I.E.(Aust.), Grad.I.C.E., and G. J. B. Lee, B.E., on a visit to the Serre Ponçon dam in April 1957.

The river-diversion arrangements in use consisted of a preliminary upstream cofferdam and bottom tunnel No. 2 (see Fig. 5, on p. 179 of our May, 1957, issue). Both bottom tunnels were fully excavated, and the outlets were complete. The main upstream cofferdam was being constructed from material derived mainly from the site of the balancing reservoir and placed by 25 cu. yard Euclids. Underwater excavation in the future balancing reservoir was by dragline excavators.

On the site of the main dam grouting of the 4,300 sq. m. of cut-off curtain in the alluvial part of the foundation was complete; because of the weakness of the grouted alluvium near the surface, however, the top layer of the cut-off curtain was being removed, to be replaced by the watertight core (Fig. 14). Some unsuitable material was also being excavated from the dam site, upstream of the core, near the Serre de Monge. Part of the material excavated on the site of the balancing reservoir had been placed in the original river bed upstream of the core, but no fill had been placed either in the core itself or in the dam foundation downstream of it. In addition to a total of 30 Euclids on the site, 25 of which were working, there were also some British 4 cu. m. Aveling Barford dump trucks in use for moving earth. The site layout, particularly as regards roads, had been excellently planned and was working efficiently.

The concrete arch roof of the power house, 210 m. long by 20 m. wide, had been completed, and excavation was proceeding downwards—20 m. out of the final depth of 40 m. had been removed.

The valve house upstream of the power house was being excavated.

The transformer house downstream of the power house (shown, but not labelled, on Fig. 5) had been excavated, and concreting of the roof was in progress.

The office building and workshop had been constructed, and a central concrete mixing plant erected nearby.

The estimated date of completion of the dam was given as 1960. At least two years would be required thereafter to fill the reservoir.

NOTE.—In Part I of this article, published in the April issue, the mean annual flow of the Durance at Cadarache should have been stated, on page 150, to be 6,150 *million* cu. m.

* A. Decelle, M. Guelton and R. Muller-Feuga, "Example of an Artificial Supply to the Ground Water in an Alluvial Basin of 50 sq. km. Area on the Lower Durance" (in French), Second Congr. Int. Irrig. Drain., Algiers, April 1954, Quest. 6, *Report* 6, p. 6.113.

† See, for example, A. A. Fulton, "Civil Engineering Aspects of Hydro-Electric Development in Scotland," *Proc. Inst. Civ. Engrs.*, Part I, Vol. 1, No. 5, May 1952, p. 258; and discussion by F. Newhouse, *ibid.*, p. 285.

Correspondence

Hydrology of the Durance

To the Editor of WATER POWER.

Your contributor's commentary on flood analyses for Serre Ponçon is most interesting and valuable. The question which naturally arises is why, if Gumbel type methods "possess the sound theoretical basis of extreme value theory," the estimated larger extreme values should, by observation, be so grossly in error on the Durance.

I raise this point because I do not think the Durance is unique in this respect, and as a practising hydrologist my experience is that the larger extreme values often tend to be nearer a simple straight line extrapolation than to the values predicted by a Gumbel type analysis.

It is extraordinary how often the statistically improbable event seems to happen in hydrology and there is obviously something still to be contributed to such analyses. Perhaps the weakness is in the unqualified presumption that these events are random, and always in the same family.

N. J. COCHRANE, B.Sc., M.I.C.E., F.R.MET.SOC.

Power from the Wind

Percy H. Thomas presents a " pilot thesis " for a programme of wind-power development in conjunction with hydro systems

"THE story is told of a vessel off the north-east coast of Brazil, short of water. On signalling a passing ship for help, she was told to drop a oucket over the side; they were off the mouth of the Amazon River and the water around was fresh."

"Eventually, why not now ? "

These quotations are texts for a thesis looking to a new source of electric power. This thesis is addressed to the entrepreneurs of the electric utilities, upon whom rests the responsibility for adequate, future, low-cost supplies of power, and, no less, is addressed to householders and managers of industry. A quick look at the present situation indicates a rapidly increasing power demand with uneasiness at the growing costs of power from fuel plants, somewhat relieved by a general hopefulness of abundant low-cost energy from nuclear plants, rather uncertainly predicted for some date between 1960 and 1980.

The "moral," or conclusion of this thesis is the fact of the present existence of a technique adapted to the generation of electric power from the wind; a technique that has been developed through the last twenty years, though generally unrealised by utility planners. This plan of operation involves the utilisation of the energy from the wind to obtain firm power from the aggregate of the contributions of scattered batteries of wind turbines, generated individually intermittently, as the wind blows, but withdrawn for use at will, as firm power on any normal load curve. It must be pointed out that this technique is available only in our major widespread well-interconnected electrical networks with a certain proportion of hydro storage. Even then the wind-supplied portion of the total capacity is limited to some fraction of the whole, probably not more than one half. This limitation is to assure that the natural diversity between wind turbines, well separated, and the fluctuation-equalising capability of reservoir-supported hydro capacity are sufficient to convert the local, unpredictable wind energy to system-wide firm power.

Beyond the test confirmation of the estimated performance and cost of construction of the available designs of large-capacity aerogenerators (7,500 to 10,000 kW), the exploitation of wind energy is now ready to proceed; no further development work is necessary, as no equipment and no procedures not now in general use are included in the proposed technique. This technique has been built up, step by step, by various groups working more or less independently. In the U.S.A. and in Germany, the natural patterns of the wind have been determined by the study of millions of Weather Bureau wind-velocity readings over 30 to 40 years. Continuous records of wind velocities have been taken for several years at what have been selected as favourable wind-turbine sites over England, Scotland, Wales, Ireland, and the Orkney Islands, a most valuable and satisfactory research. Actual operating experience with the delivery of energy from the wind in the field to a normal utility system under routine conditions (up to 1,400 kW), and with winds reaching 50 miles per hour, was gained with the 1,250 kW Smith-Putnam wind turbine, installed on Grandpa's Knob mountain (Vt., U.S.). This operation was brought to a close, although intended for continuous service, by a serious mechanical failure and by the exhaustion of the available funds. This situation now awaits the appearance of the next pioneer. As a result of the Smith-Putnam experiment, the much-needed long-overdue critical analysis of the aerodynamics of the wind turbine was undertaken. On account of the inadequacy of the existing textbook treatment of the unique aerodynamics of the wind turbine, it was necessary to go to the classic aerodynamic researches of the government agencies in England, the U.S.A. and other countries. The result was a treatment of the problem to secure more than double efficiency compared with that attained in the case of the Smith-Putnam turbine, a most significant gain.

As a result of this advance in the treatment of the aerodynamics; of some important structural changes (including placing two wheels on one tower), and of a much simplified operating control, it has been possible to design a prototype aerogenerator with an indicated capacity of 7,500 to 10,000 kW—an output not far from the optimum capacity for the proposed technique. After these explanations it is possible to state the technical basis for the above statements.

Wind Patterns

The pattern of the energy of the wind through the years, taken as the total of the annual energy recoverable by the above aerogenerator is far more nearly constant than the pattern of stream flow in power rivers, the total recovered in the year not being expected to drop more than 10% or 15% below the long-time annual average. For this reason long-time records of the wind velocities at particular sites are not necessary provided that the pattern of the neighbourhood is known.

The monthly average recoverable power varies through the year in a smooth, rather consistent curve, with the outstanding characteristic that the major portion of the energy falls in the half year of low stream flow (perhaps two thirds in the wind's flush six months). Thus, with a proper combination of water and wind units the value of the year's minimum firm capacity tends to equal the minimum of the average of the two, well above that when the two sources of power are in separate systems. Incidentally, a considerable amount of the seasonal reservoir capacity is freed from the hydro duty.

Firm Power from Wind Energy

Under the strict limitations stated, the wind energy delivered by the individual turbines as the wind blows may be withdrawn from the network without major

adjustments and utilised on any normal load curve as needed through the year. This favourable feature follows from the very effective diversity between sites over these large networks, and from the well-known capability of hydro storage to equalise variations of supply for moderate periods of time. The pattern of the wind with its annual variations complementary to those of hydro plays an important part here.

Reduction of Transmission Duty

The proposed technique calls for the installation of aerogenerators (in batteries, if desired) in windy areas, reasonably close to local load centres, so that the major portion of the wind energy does not leave the local low-voltage distribution lines. This plan is facilitated by the fact that the wind-supplied energy is only a fraction of the total.

It is definitely favourable to make all units of the same design and capacity, or, alternatively, one of two or three designs. The effect of this spreading of generating units is to eliminate as much as possible of the heavy burden of transmission from giant stations, together with the expensive switchgear and the breakdown hazard involved. There have been a number of serious interruptions of this sort within the last few years. This decentralisation and great simplicity must represent some definite item of saving.

Cost of Power

The cost of power, both installation and operation, is likely to be definitely the lowest for utility power, except, perhaps, for some of the most favoured hydros. The construction cost of the aerogenerator here under discussion has been estimated as somewhat below that of an equivalent steam plant, without the benefit of the plan for the long-time continuous installation of standard units. The operation of the wind turbines will be semi-automatic, and needs only intermittent supervision. There is further the advantage that nature furnishes the energy free, on the site, and not subject to increase of price or rationing. It constitutes an effective and welcome "anchor to windward."

Installation Programme

Wind energy offers a tempting installation programme, having little in common with the undertaking of the modern giant steam plant. The wind units are installed as a very modest long-time continuous operation, using permanent trained crews and adequate equipment, foundations being a very minor consideration. The wind capacity increases only as the load grows, with the units installed as, when, and where the load appears, offering maximum flexibility. Individual units require from six to nine months for installation, and will thus be earning well within one year. This programme should cut a large slice of the overall cost, not including the reduced overhead.

The possibility of a saving of a different type from such a programme appears, perhaps controversial. The annual costs are modest and relatively evenly spread over the years. If it be possible to take this expenditure from current profits, there will be no further charges to amortisation. The cost of setting up and administering an amortisation project for the life of an installation is considerable, over and above the accumulation of the amount of the expenditure. Further, no payment of interest is required; a major item.

The representations of this thesis having been set forth, it may be appropriate to point out that, once the prototype aerogenerator has been built and tested successfully, there seems to be every reason to anticipate the development of the exploitation of wind energy, in an orderly manner, up to the total of the suggested fractional limit, that is, in favourable countries, ultimately up to some tens of millions of kilowatts. With some such figure for the U.S.A., figures for wind-power capacity of appropriate size could be expected in other industrialised countries with known windy areas, such as France, Germany, Scandinavia, etc., to say nothing of the exceptionally favourable wind pattern in the British Isles.

The import of the "texts" quoted above is now clear; why should not the good ship "Electric Utilities" drop a power bucket over the side and draw freely from the abundant stream of free wind energy.

The start of the wind-power programme is handicapped by the fact that the plants of present fabricators of electric generating machinery are not adapted to the manufacture of high-efficiency aerogenerators. Manufacturing plants with the equipment required for such wind units will be set up only when the demand appears. This should be only a temporary delay, since, no doubt, there will be ample orders for both types of apparatus for some time, and until such time as the promised atomic plants are ready. However, when that time comes, it may be speculated that it will not then be the wind units that will yield. Further, no doubt, a stronger incentive would exist for the electric utilities now under commission, if some item should be incorporated in the regulated return to the utility, recognising improvement in efficiency of operation or lower power costs.

It has been said that a stranger standing in the crowd on Whitehall could not give away a brick of solid gold; it seems that this might even be so.

Model Hydro-Electric Set

An interesting working model of a hydro-electric set is now on view in the Main Hall of the Science Museum, South Kensington. It consists of a 0·85 h.p. Gilkes Pelton wheel driving a 500 W Bruce Peebles generator. Water pressure is supplied by a pump in the base.

The runner, jet and deflector can be clearly seen through the perspex cover, and the load, consisting of five 100 W lamps, can be controlled in stages, thus demonstrating the action of the governor with sudden load changes. A complete switchboard with miniature control gear is provided and the model is a working example of a full-size hydro-electric set.

Earth-Moving Equipment. Two illustrated folders issued by Allis-Chalmers of Milwaukee describe the many attachments that are now available to enhance the versatility of their HD-6G and HD-11G tractor shovels. These include such tools as buckets for various purposes, rippers, lift forks, trench hoes, rock forks, drag buckets, crane hooks and bulldozer and angledozer blades. The sole distributors for plant in the United Kingdom are Mackay Industrial Equipment Limited of Feltham, Midlesex.

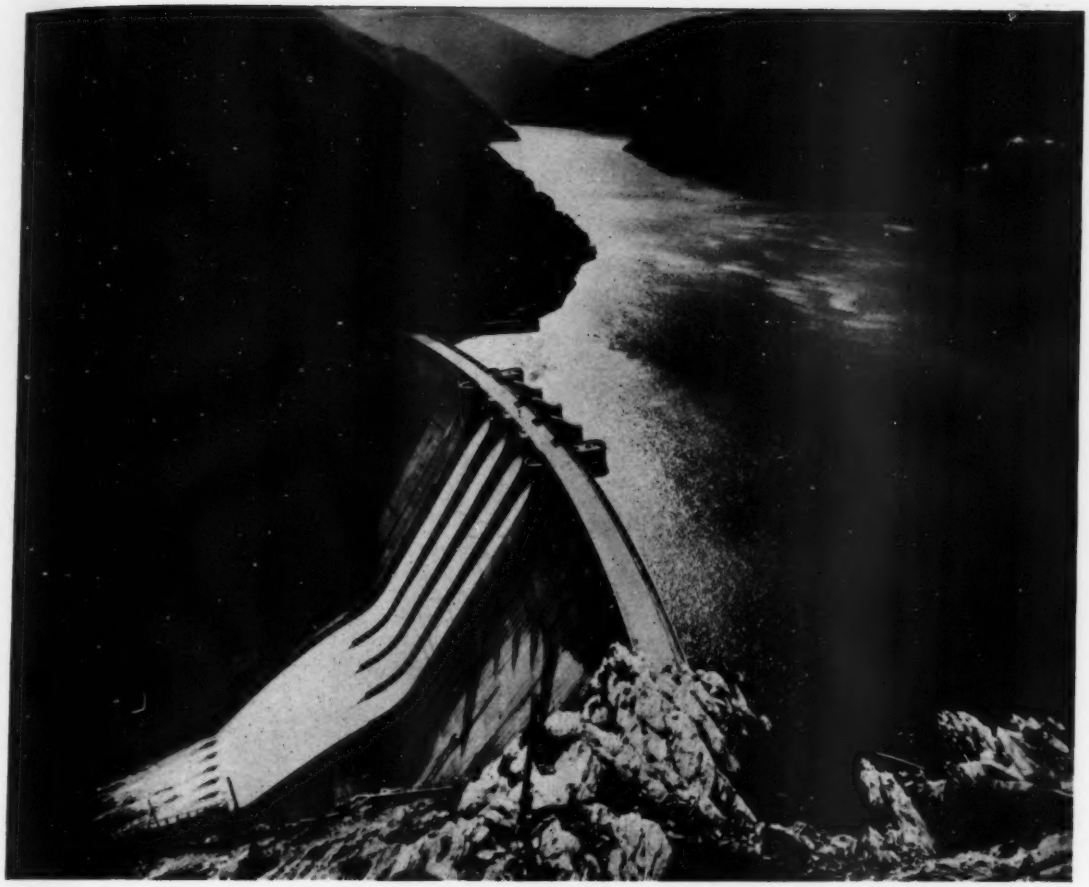


Fig. 1. The Salime reservoir and dam

Salime Power Station

In this Spanish scheme an unusual design of station has been evolved to handle exceptionally large floods in a narrow valley

PART of the extensive hydro-electric developments that are taking place in Spain is the full exploitation of the river Navia in Asturias. This work is being undertaken jointly by two supply companies in the North of Spain, Electra de Viesgo S.A. and Hidroelectrica del Cantabrico S.A., whose headquarters are respectively at Santander and Oviedo. The construction work is being carried out by a subsidiary company named Saltos del Navia en Comunidad, created by these two companies for this purpose.

The river Navia rises in the mountainous district between Lugo and Ponferrada and flows northwards to enter the Bay of Biscay at a small fishing village, also called Navia, about 90 km. west of the port of Gijon. The river is short, judged by Spanish standards, being only 115 km. long, but in this distance it falls 400 m. A total of five power stations are planned and these will help to supply the mining and industrial districts of Northern Spain, including the areas around Oviedo, Ujo and Santander. These five stations are (a) Doiras, built by Electra de Viesgo in 1934, containing three generating sets each of 20,400 metric h.p., 18,000 kVA, (b) Salime, at Grandas de Salime, containing four sets each with a maximum output of 50,000 metric h.p., (c) Silvon, which will take its water from the Doiras reservoir, the capacity and head of which is being increased by raising the dam crest by 3 m. This station will contain initially one set of 44,750 metric h.p., 35,000 kVA, space being left for a second set, (d) Suarna, the farthest upstream, the project for which is nearing completion, and (e) Arbon, a station planned downstream from Doiras to complete the exploitation of the river.

The English Electric Export and Trading Company

was awarded the contract on January 1, 1949, for the supply and erection at Salime power station of the four main turbine inlet valves, the four main vertical Francis-type turbines with their draft tubes and auxiliary equipment, the four main 35,000 kVA alternators, the four main transformers, all 380 V, 11 kV and 140 kV switchgear and the 11 kV power cables between the alternators and the 11 kV cubicles. Subsequently, in November 1955, the contract was placed with The English Electric Company for the first generating set for the Silvon station.

Salime power station was officially inaugurated by General Franco in August 1955 and it is at present being used as a peak-load station. Paintings on the power house walls depict the changes that have taken place in the Navia river valley throughout the ages and illustrate the labours involved in harnessing the river to provide abundant electrical energy.

Salime Dam

The Salime dam is of the arch-gravity type, having a uniform triangular section throughout its length with a slope of 5% on the upstream face and 72% on the downstream face. The dam crest lies on a curve of 400 m. radius and its height above the foundation is 131·5 m. The horizontal length of the crest is 250 m. and its width is 9 m.

The penstocks for the four turbines are embedded throughout their length in the structure of the dam, each being about 90 m. long and having an internal diameter of 2·5 m. Each pipe has an intake screen and an intake butterfly valve, the latter being accessible through a gallery in the dam. At the bottom end, each pipe is connected to an English Electric "Straightflow" main turbine intake valve.

Power Station and Spillway

One of the interesting features of Salime hydro-electric power scheme is the design of the spillway, which flows over the power station into a stilling basin. This unusual layout was necessary because of the local topography.

The river Navia flows for the most part in a deep narrow valley through high mountains, the total catchment area being 1,806 sq. km. It is fed by melting snow as well as by springs and rainfall, under which conditions severe floods are to be expected at times, and the Salime spillway had to be built for a maximum flow of 2,000 cu. m. per sec., despite the fact that the average flow of the river at Salime is only 51 cu. m. per sec. Therefore, at maximum flow the spillway dissipates about a million horsepower and this must be done in a very narrow valley where there is a danger of landslides, and also avalanches in winter, due to the steep inclination (about 45°) of the strata and the slaty nature of the rock.

As there was not sufficient space for the power station and spillway side by side at the foot of the dam, the power station was placed there and the spillway carried over its roof, discharging into a stilling

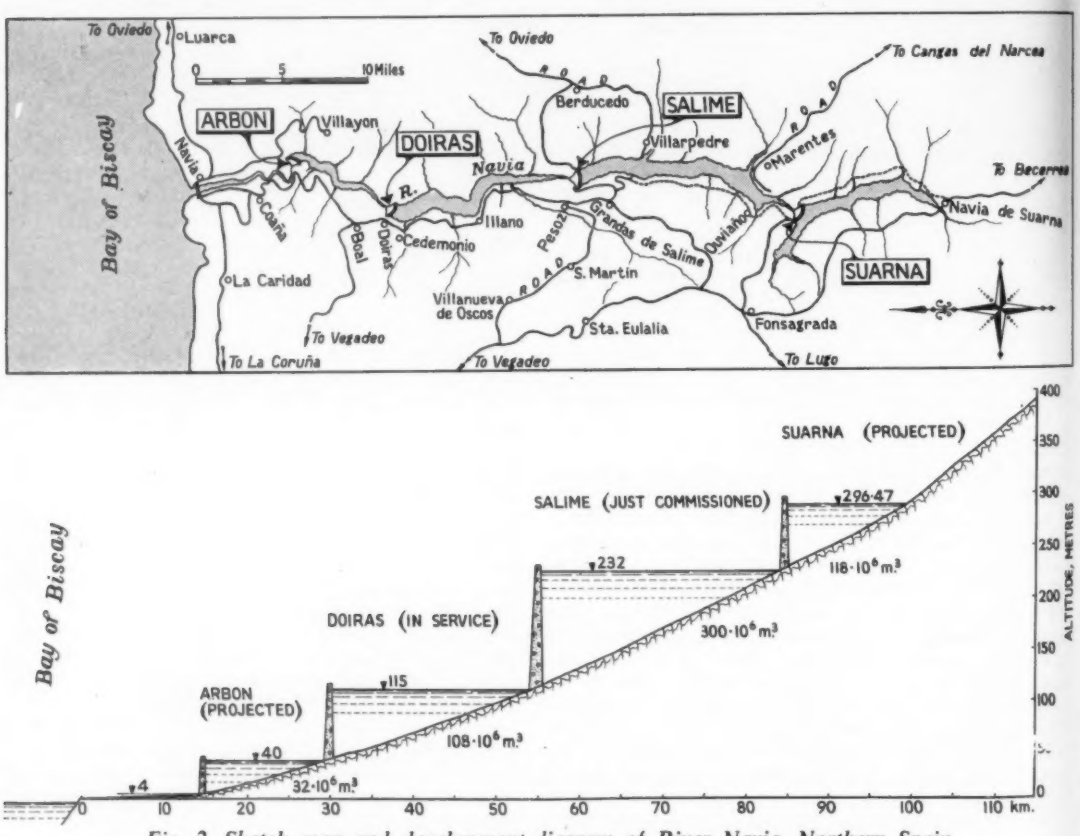


Fig. 2. Sketch map and development diagram of River Navia, Northern Spain

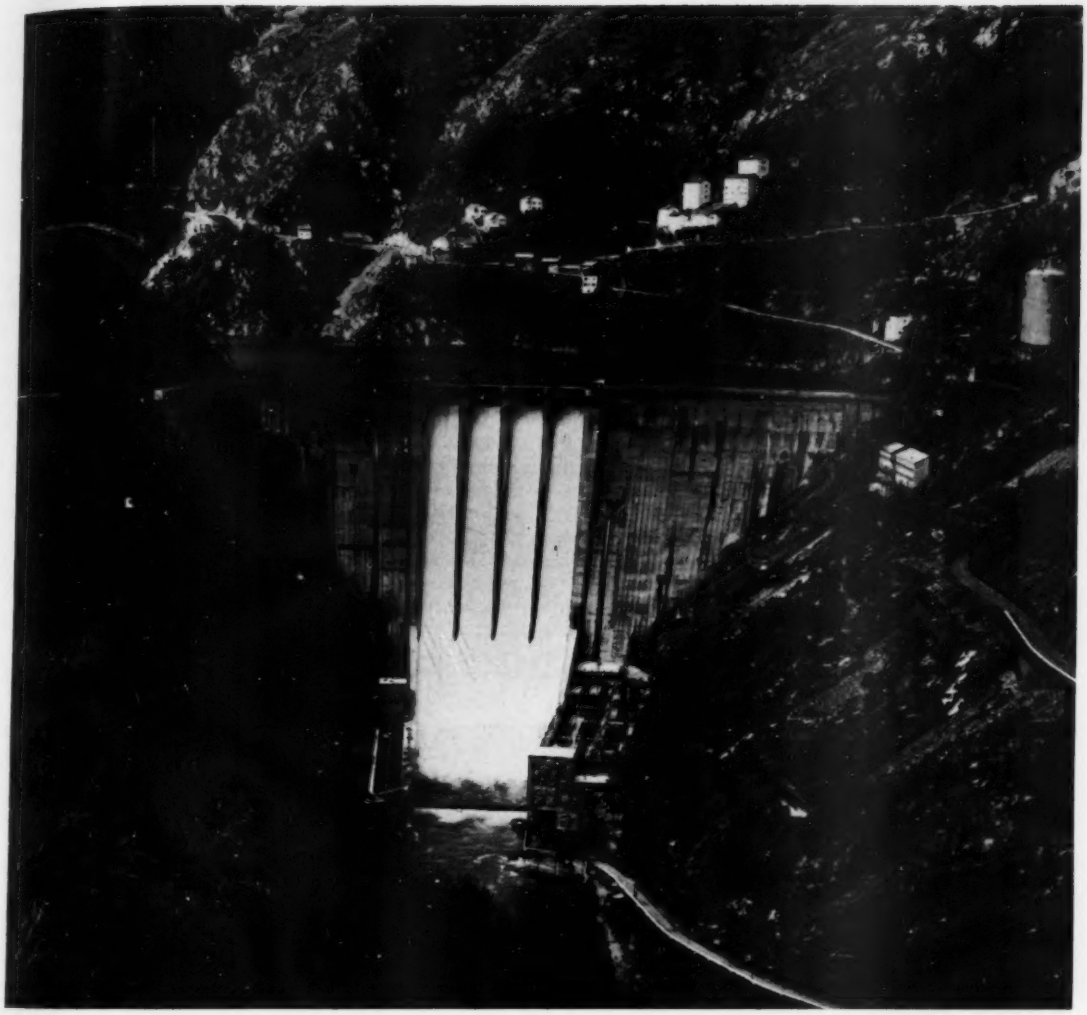
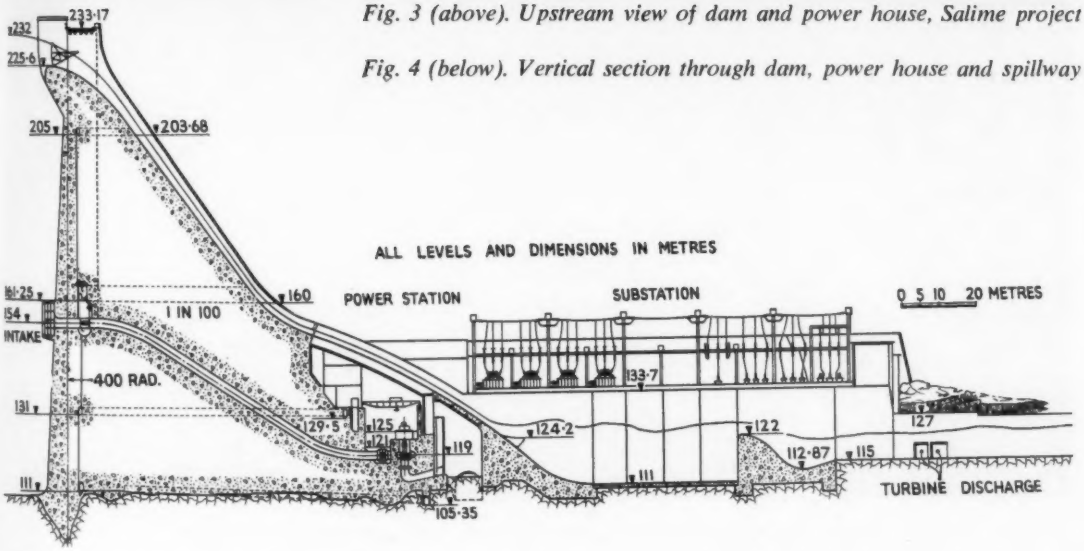


Fig. 3 (above). Upstream view of dam and power house, Salime project

Fig. 4 (below). Vertical section through dam, power house and spillway



basin. The water slides into this and flows along its bed until turned back on itself by the downstream retaining wall. A row of "dragon's teeth" is located at the meeting point of the spillway and stilling basin so that the water is aerated before entering the stilling basin, thereby preventing cavitation of its floor. The spillway is shaped to give a slight lift to the water as it passes over the power house in order to relieve to some extent the pressure at that point.

The surface of the spillway conforms to the curvature of the main dam. For this reason the four main generating sets in the power house lie on an arc of 310 m. radius. Consequently, the station overhead travelling crane rides on a curved track and has larger-diameter wheels on the upstream end than on the downstream to compensate for this curvature.

Three main transverse bays are provided beneath the spillway. The power house occupies the middle bay, the tailwater chamber the bottom one, and the upstream bay houses the main control room containing control, metering and relay boards and all the 380 V switchgear. A platform was made on the left bank of the river alongside the stilling basin to house the four main transformers and the 140 kV switching station.

The water in the tailrace chamber passes through a free-flow tunnel of 7 m. internal diameter, running underneath the substation, and discharges into the river just downstream from the counterdam of the stilling basin, thus ensuring stable tailrace conditions.

Layout of the Power Station

The layout of the power station follows the normal English Electric one-floor arrangement, in which all parts of the plant and equipment, including the main valves, come under direct access of the crane. The turbine centreline is at an elevation of 119 m. above sea level, and the station floor at 121 m.

The width and height of the power station had to be reduced to the utmost so that the spillway could be kept as low as possible, and by adopting a curved longitudinal horizontal axis instead of the normal straight axis, a considerable saving in these dimensions was obtained. In addition, two important departures from standard machine design were made to keep to a minimum the crane-hook height necessary for lifting the rotor out of the stator; the turbine-alternator shaft was divided into three sections instead of the usual two, and the pilot exciter was partly telescoped inside the main exciter. An important consideration when endeavouring to keep the height and width of the station to a minimum was that under no circumstances was it permissible to encroach on the 72% downstream profile of the dam.

The roof of the power house slopes due to the spillway. To keep the machine room dry, an apron was placed between the spillway channel and the power house roof to collect any seepage water.

Provision has been made for dismantling the turbine runner from below by making the throat of the turbine draft tube removable so that the runner can be

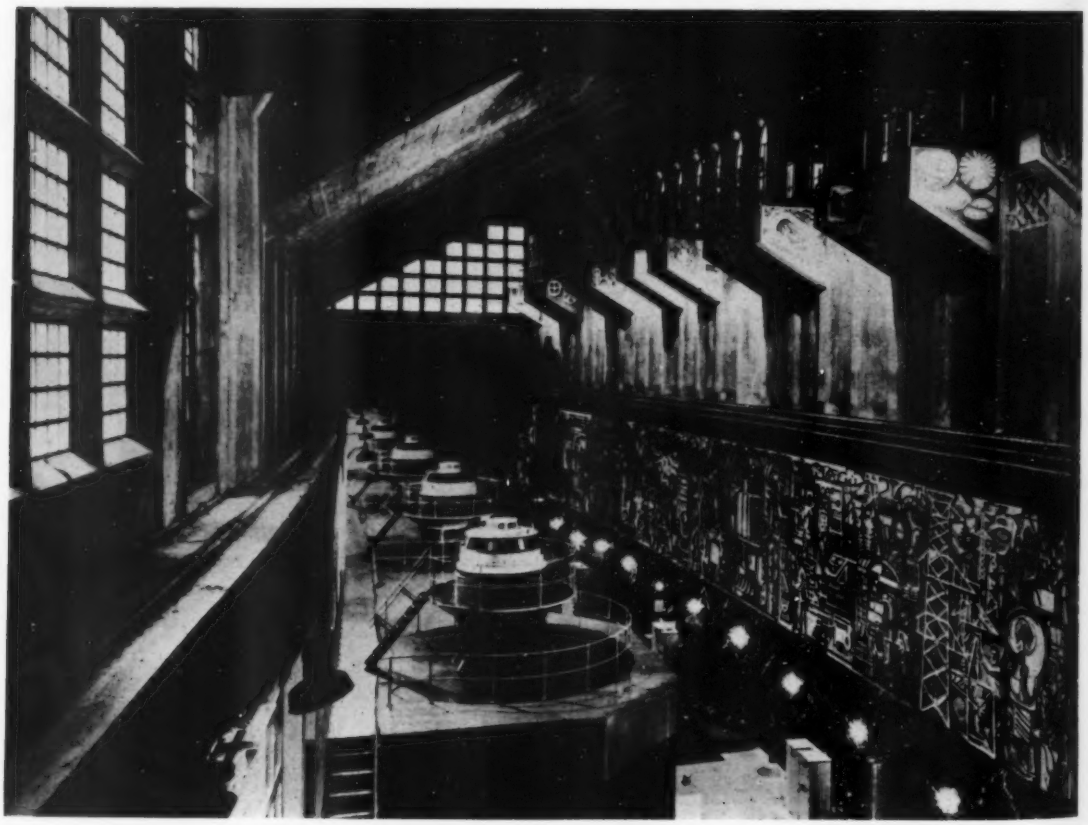


Fig. 5. Interior of Salime power house showing four 35,000 kVA sets

lowered on to a special truck and then run out on rails to a pit, where it comes directly under the crane. A major maintenance overhaul of the turbine can thus be made without disturbing the alternator in any way.

Turbine Inlet Valves

The main turbine valves are of the English Electric "Straightflow" type, having a bore of 2,130 mm. These valves present a straight and smooth pipe bore to the water when open, but are always capable of closing safely in emergency since a hemispherical valve door cuts through the water without deflecting it. Water hammer is avoided by regulating the movement of the valve-operating servomotor by a travelling control

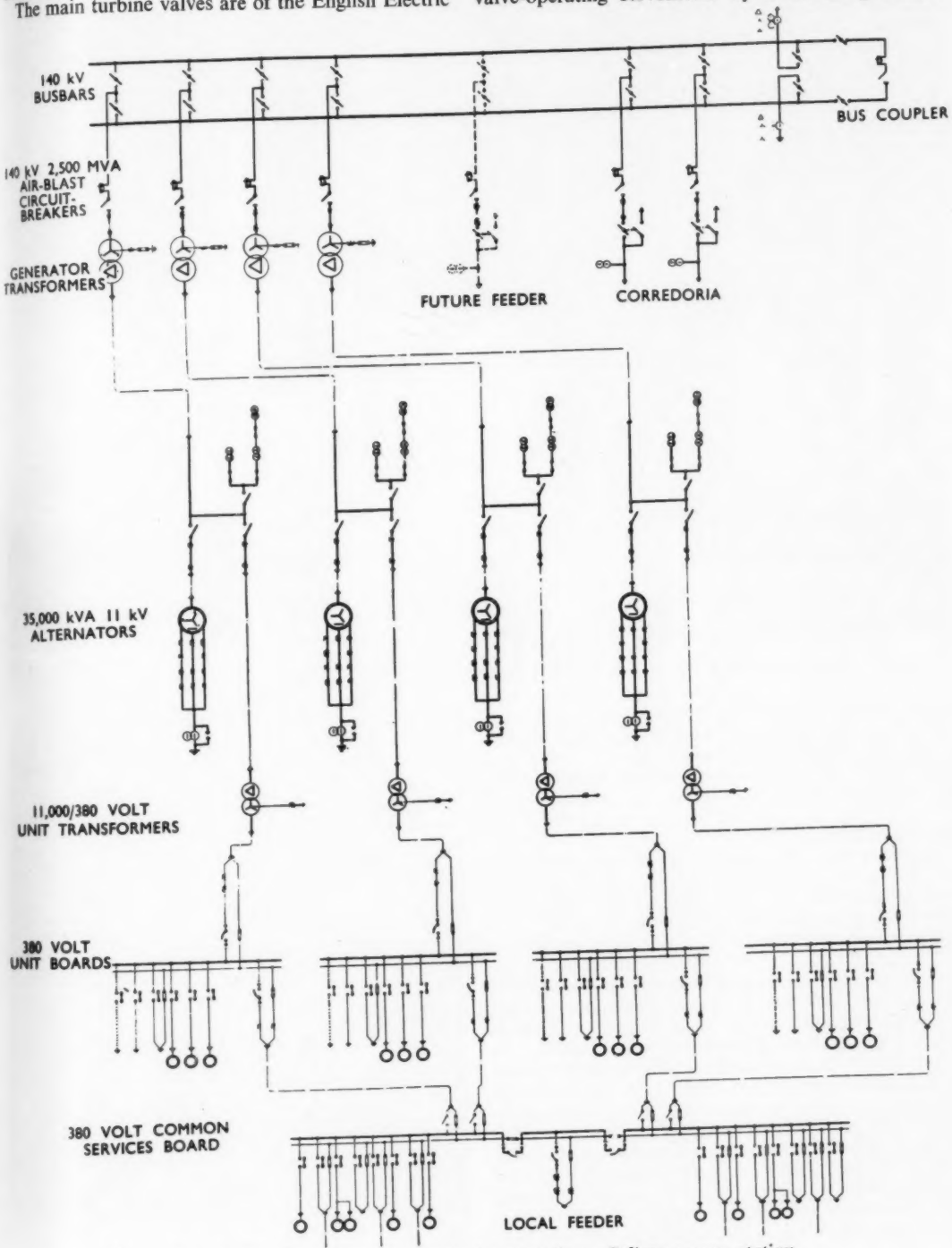


Fig. 6. Diagram of main electrical connections, Salime power station

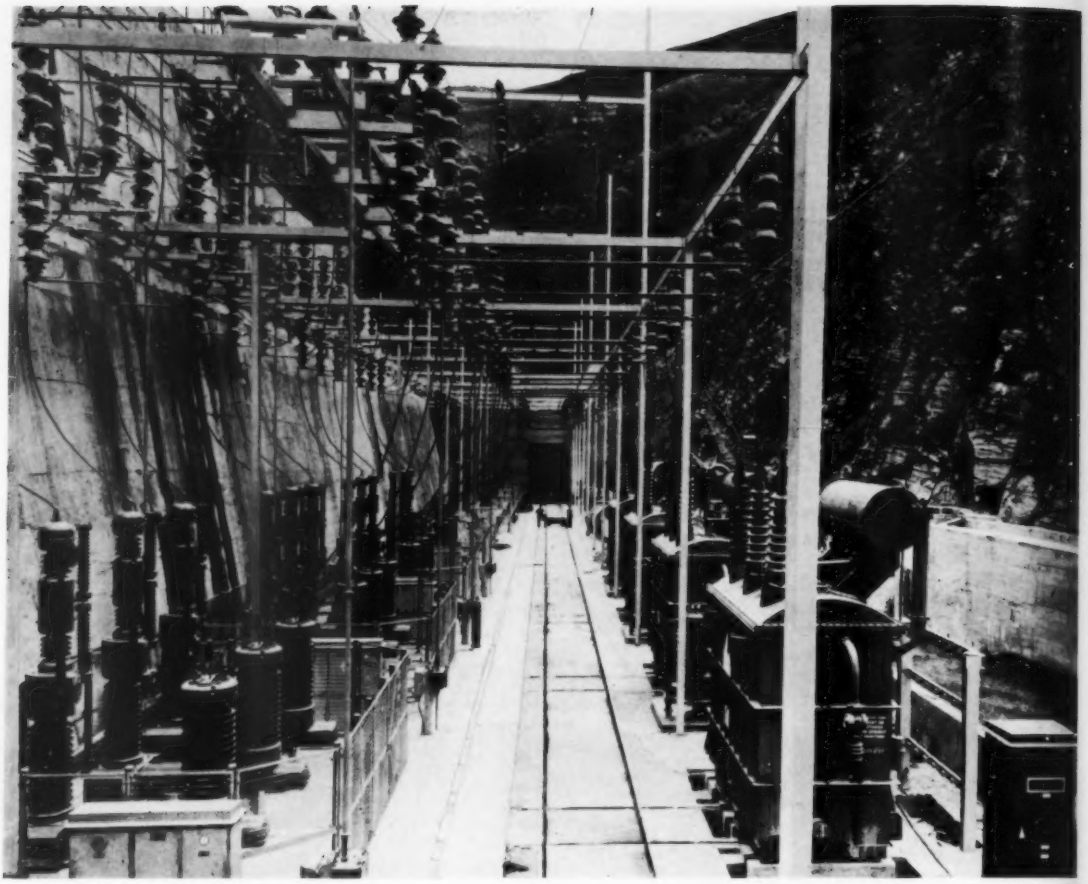


Fig. 7. Outdoor substation for 35,000 kVA transformers and 140 kV, 2,500 MVA circuit breakers

screw which progressively diminishes the speed of closing. A double rubber seal is provided on the valves. The second seal enables inspection or replacement of the main rubber seal without emptying the water in the pipeline.

The Turbines

The four main turbines are of the vertical Francis reaction type running at 300 r.p.m., each giving a maximum output of 50,000 h.p. under a net head of 112·5 m. The minimum working net head is 69 m., under which conditions each turbine gives 21,000 h.p.

The spiral casing of the turbine was welded to the speedring in the works and then the whole assembly was divided into four parts for dispatch, since the limits for transport to site were fixed at 47 tons or 5 m. wide × 4 m. deep due to the difficulties of approach to the power station. These sections were finally bolted and welded together at site and then tested, before being embedded in the concrete foundations. The runner was fabricated, the runner blades being of stainless steel formed to shape before being welded to the runner crown and skirt. It has steel labyrinth water-sealing rings. The guide vanes and their trunnions are of mild steel.

The regulating ring is of welded steel, with gunmetal gliding pads, and it is provided with cast-iron guide-vane levers and links and two steel rods directly connected to the operating servomotors. The governor follows the usual English Electric principle, in which an actuator is driven by a pendulum motor and incorporates a speed-adjustment device for synchronising and loading, and an underspeed device. It controls an oil-operated pilot servomotor which is itself fitted with a device for shutting down due to overspeed, low oil pressure, the operation of the electrical protection, or by pushbutton from the control room. The pilot servomotor operates the main distributing valve which controls the oil to the twin guide-vane servomotors.

The Alternators

The four main alternators give an output of 35,000 kVA each at 0·9 power factor 11,000 V 50 cycles, the speed being 300 r.p.m. They are of the vertical-shaft two-bracket type, a combined thrust and guide bearing being mounted on the upper bracket above the rotor and a second guide bearing on the lower bracket below the rotor.

The stator frame was divided into two parts for transport to the site. The rotor was assembled at site by shrinking the steel hub packets on to the shaft and then fitting the salient poles on the hub. Both the poles and the hub are dovetailed and fitted with taper

side keys in the slots in the rotor hub to facilitate removal for repairs.

Closed-circuit cooling is employed for the machines, the air being circulated by fans attached to the rotor and cooled by six water-cooled air coolers arranged tangentially outside the stator frame, instead of radially, to reduce the overall diameter as much as possible.

A governor alternator is mounted on the extension shaft directly above the thrust bearing, to supply a synchronous motor which drives the turbine-governor actuator pendulum. The main and pilot exciters are mounted on the same shaft, above the governor alternator.

The whole weight of the revolving parts, plus the vertical hydraulic thrust, is carried on a thrust bearing of the pivoted-pad type, mounted on the upper bracket, the load being transmitted through a thrust collar which is lightly pressed on to the shaft and secured by keys. The pads are pivoted to enable them to tilt freely in any direction and are also adjustable to ensure that each carries the same load. The upper guide bearing also has pivoted pads which run on the polished vertical surface of the thrust collar. Both bearings run in a common oilpot through which the oil is circulated by an a.c. motor-driven pump, with a d.c. motor-driven pump as a standby. A second guide bearing, also of the pivoted-pad type, is mounted on the lower bracket, below the rotor, and this is included in the same lubricating system as the combined thrust and upper guide bearing.

The Transformers

The four main transformers are three-phase units each rated at 35,000 kVA and having a no-load ratio of 11/140 kV, the 11 kV winding being delta connected and the 140 kV star connected. Advantage has been taken of the fact that the neutral point of the system is solidly earthed to provide graded insulation on the 140 kV windings, with tapping points connected in the neutral end of the high-voltage coils to give $\pm$ 2½% and 5% voltage variation. The tap-changer is manually operated from the exterior of the tank, and is padlocked to ensure that it is only operated by a responsible engineer.

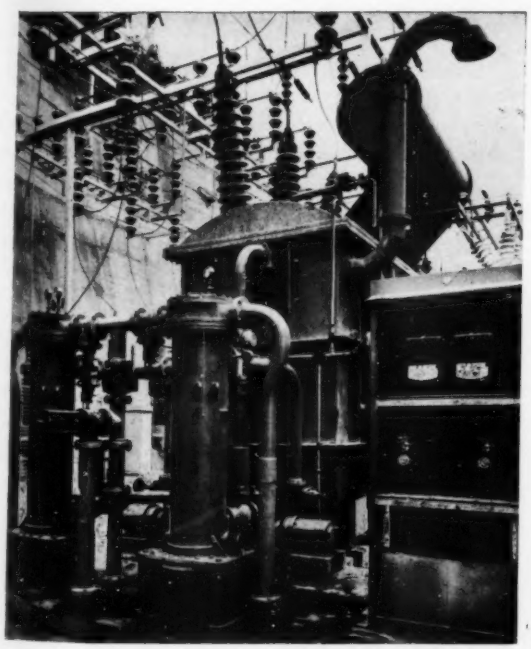


Fig. 8. One of the four 35,000 kVA 11/140 kV generator transformers

The transformer oil is cooled in two oil-water heat exchangers, each of which is adequate for continuous full-load operation. Provision is made to change from one cooler to the other without interruption of the circuit or change of load. The oil is circulated by means of a pump, which keeps the oil pressure in the cooler above that of the water to ensure that in the event of leakage there shall be no risk of the oil becoming contaminated with water.

There are four 800 kVA unit transformers, each with a no-load ratio of 11,000/380 V, and these were manufactured by a Spanish company. Each is capable of supplying all the auxiliary and common services requirements of the station.

Switchgear

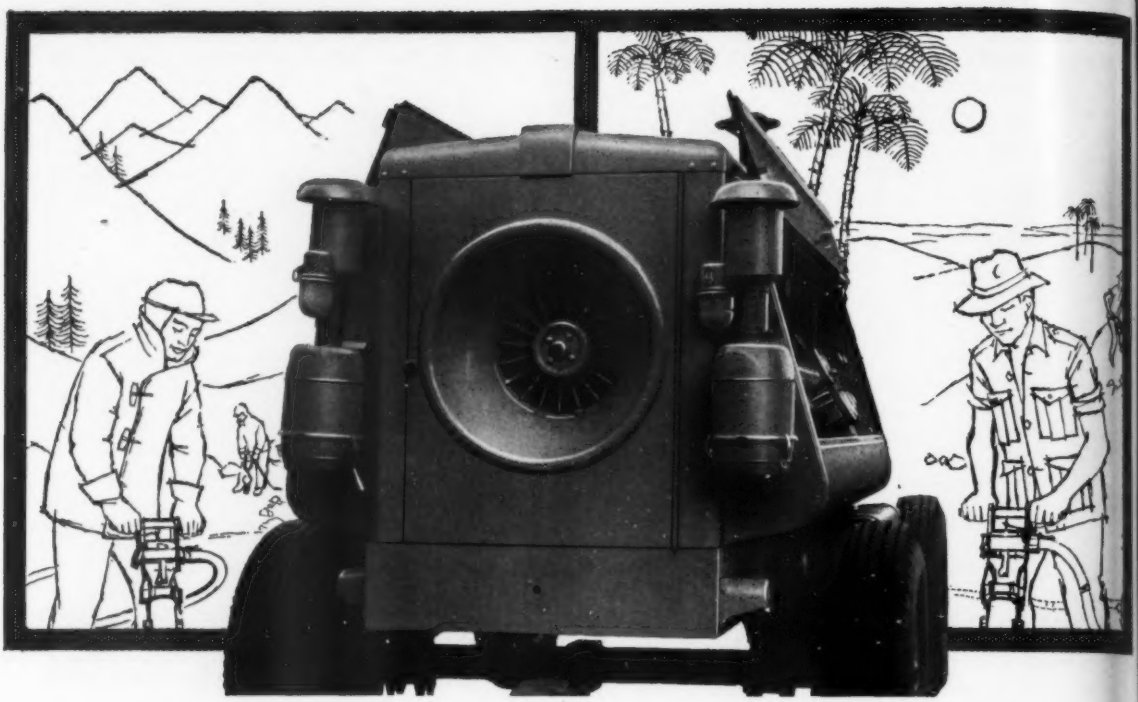
The unit arrangement was adopted for the power station, in which each set normally runs independently of the others and supplies its own auxiliaries at 380 V by means of a unit transformer connected direct to the alternator.

The 11 kV switchgear consists of isolators housed in cubicles for isolating each alternator from its main transformer and also for disconnecting the feed to the unit transformer if desired.

With the exception of the governor oil pump, alternator and turbine main lubricating-oil pumps and the alternator heaters, all the main machine auxiliaries and other station and local services are supplied at 380 V from the common-services board which is fed from any one of the four 380 V unit boards. These three oil pumps and the alternator heaters for each set are supplied direct from the unit board of the set. The unit boards and the common-services board consist of air-break draw-out type circuit-breaker units and "Combination" fuse-switch units. There is at present no auxiliary generating set to provide an alternative supply to the common-services board, although provision has been made for such a supply to be connected to this board if considered desirable at a later date. If the station shuts down completely it is restarted by isolating the alternator of one of the sets and feeding from the 140 kV busbars through a main transformer and the corresponding unit transformer to the unit board and from there to the common-services board.

Because of the narrowness of the site for the outdoor substation alongside the stilling basin it was essential to use a "high" type arrangement in which the isolators and busbars are vertically above the circuit-breakers, instead of adjacent to them as in a "low" station. The station has duplicate 140 kV busbars.

The 140 kV circuit-breakers are of the English Electric air-blast type, with two interrupters in series per phase, having a breaking capacity of 2,500 MVA. All the feeder breakers are provided with high-speed auto-reclose control. Duplicate air-compressor sets are provided to supply all the requirements of the substation.



Air-cooling proves best in any climate

Whatever the climate, in any working conditions, portable compressors with air-cooling for both engine and compressor have proved superior in every way to water-cooled portables. There are no cooling agents to overheat or freeze up. The air-cooled units allow a higher working temperature, which means far less wear on cylinders, pistons and rings, especially if high sulphur content diesel oils are used. And they reach working temperature in half the time taken by water-cooled units—so starting wear is cut down considerably. As most of the troubles in water-cooled units arise from defects in the cooling system, *the mechanical reliability* of air-cooled units is much greater. Moreover their lower weight makes transportation and handling easier.

THE MOST COMPLETE RANGE OF AIR-COOLED COMPRESSORS IN THE WORLD

Atlas Copco compressors with full air-cooling, range from the 600 cu./ft. per minute type illustrated to one delivering 36 cu./ft. per minute—the largest and most comprehensive range in the world.

Every model in the range has a standard engine cylinder, and there are only a few types of compressor cylinder. This ensures simplified spares stocking and easier service and maintenance.

It should be noted that most Atlas Copco air-cooled portables have engines manufactured by *Deutz*—the world's leading firm in the design, development and manufacture of air-cooled diesel engines.

The Atlas Copco Group puts compressed air to work for the world. It is the largest group of companies specialising solely in the development and manufacture of compressed air equipment. It embraces Atlas Copco companies or agents manufacturing or selling and servicing Atlas Copco equipment in ninety countries throughout the world. For further details of the equipment featured here, please contact your local Atlas Copco Company or agent, or write to Atlas Copco AB, Stockholm, 1, Sweden.

Atlas Copco

MANUFACTURERS OF STATIONARY AND PORTABLE COMPRESSORS, ROCK-DRILLING EQUIPMENT, LOADERS, PNEUMATIC TOOLS AND PAINT-SPRAYING EQUIPMENT

Medium Voltage Circuit Breakers

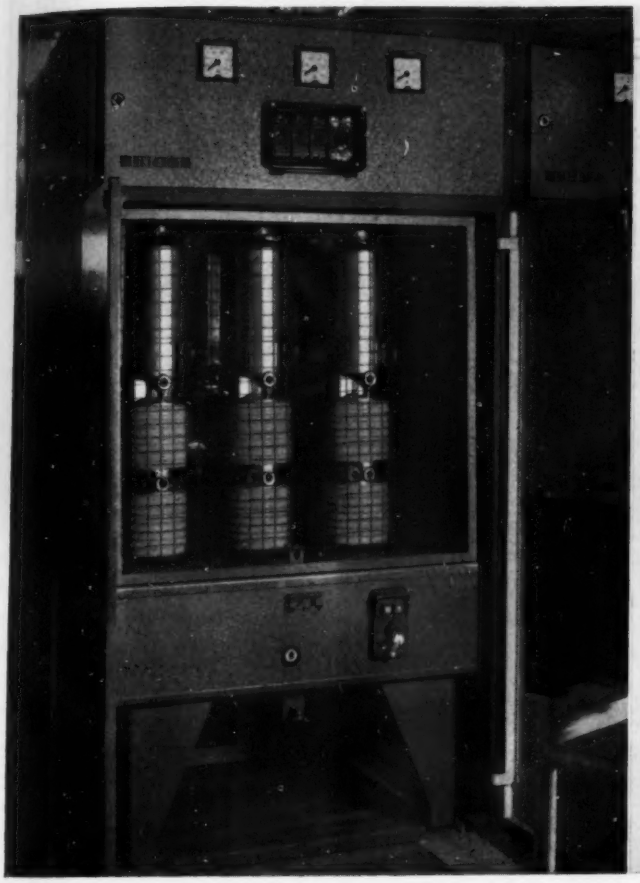


Fig. 1. Scarpa & Magnano type MT circuit breaker

Fig. 2. Sectional view of pole

A NEW range of medium-voltage circuit breakers of the minimum-oil type has recently been developed by Officine Elettromeccaniche Scarpa & Magnano, of Milan and Savona. It is known as the MT type, and supersedes the PO/L, M, P series which have been on the market for the past twenty years.

In the design of the MT circuit breaker great attention has been paid to simplicity, both in construction and in servicing requirements. Overall dimensions have been kept to the minimum to facilitate cubicle mounting or arranging as metalclad drawout units, and service safety has been a paramount consideration.

The pole unit consists of a single vertical moving contact which rises to engage a tulip-type fixed contact with four spring sectors; this fixed contact is of a new and special design. Baffles are arranged in the contact chamber to produce transverse oil flow across the upper part of the arc and longitudinal flow over the lower part. By this means the arcs from both light and heavy currents are expeditiously suppressed. A heavy-current arc builds up sufficient pressure to induce a powerful cross blast in the upper portion of the chamber, whereas the arc from a light current, which generates insufficient pressure for a cross blast, is readily extinguished by the longitudinal flow over the lower part of the contact travel. Gas from the ionised oil rises to a tall cap forming the top of the chamber. A helical baffle in this cap throws oil droplets against the walls of the cap, from which they drain back to the lower part of the chamber, and excess gas pressure is relieved by an escape valve at the top of the cap.

Maintenance of the pole units is simple. By unscrewing the cap it is possible to reach and replace the sectors of the fixed contact and the tip of the moving contact (which is a removable copper-tungsten unit screwed to the end of the contact rod) without draining out the oil. Inspection of the lower part of the moving contact mechanism naturally entails draining, but this, of course, applies only to the pole undergoing inspection.

The operating mechanism is housed entirely in the pressed-steel base of the circuit breaker, and is of the spring-operated type. No high-power solenoid or motor is required, as the opening spring is normally set by means of a 60 W motor, which, in the absence of an auxiliary supply, can be energised through a standard voltage transformer. This motor tensions

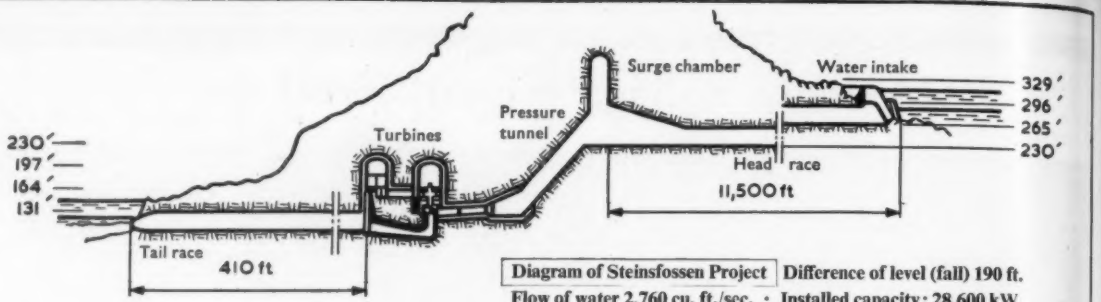


Diagram of Steinsfossen Project | **Difference of level (fall) 190 ft.**
Flow of water 2,760 cu. ft./sec. · Installed capacity: 28,600 kW.

Atlas Copco equipment at Steinsfossen

Shifts of only 8 men removed 2,300 cu. yds. per week in a 540 sq. ft. tunnel

AT THE HYDRO-ELECTRIC PLANT at Steinsfossen in Norway the contractors, A/S Høyer-Ellefsen, have chosen Atlas Copco compressed air equipment and Sandvik Coromant drill steels for all rock excavation. The head race tunnel at Steinsfossen, 11,500 ft. long and with a 540 sq. ft. section, has shown how swift, economical and simple tunnelling can be. Each week the tunnel was drifted 115 ft.—a particularly remarkable achievement for the number of men employed. This steady advance went on uninterrupted for week after week. Three shifts were worked daily *with only eight men doing all the tunnelling work*—drilling, blasting, mucking, and transportation. They were supported by two mechanics and one dump-clearer to a shift.

World-famous drilling unit

All drilling at Steinsfossen is done with Atlas Copco light rock drills and Sandvik Coromant integral steels. Specially developed over many years to work together, these drills and steels are now the most widely used drilling unit in the world. The ease and efficiency of this equipment is best illustrated by the fact that at Steinsfossen *eight men kept nine drills working simultaneously* at the face.

Speedy Atlas Copco LM 200 Loaders

At Steinfossen 240 cu. yds. of rock of big fragmentation were mucked-out per hour (effective loading time) by two LM 200 Atlas Copco Loaders. These loaders are particularly efficient because they are compact and narrow. Being railbound the minimum of space is required for manoeuvring and two can be used side by side at the face even in a relatively small tunnel. The loaders are also used for moving the drilling platform as the work proceeds. They are simple to operate and do not call for skilled workers.

Dual purpose drilling platform

Vital to the ease and speed of the whole operation was the Vinstra drilling platform which enables miners to drill from three levels. It has two movable beams on which the cars can be hung and swung across from one rail to the other. On the average car-switching took one minute.

Facts about the Steinsfossen operation

Nature of rock: Granite — Head race tunnel: 11,500 ft. long 540 sq. ft. section

Approx. advance per year: 4,900 ft. — Average advance per week: 115 ft. (128 ft. max.)

Personnel per 24 hours:

Foreman	1
Miners	24
Mechanics	6
Assistants	2 (rail laying, ventilation, air and water pipes, etc.)
Dump-clearers	3
Total:	36

Drilling equipment: 10 Atlas Copco rock drills type RH656 with pusher legs (one spare). Sandvik Coromant drill steels.

Loaders: 3 LM 200 (one spare). Loading time (including car-switching) 3.25 minutes per car of 4.4 cu. yds. capacity, i.e. 47 cu. yds. solid rock per hour and loader.

World-wide Sales and Service

The Atlas Copco Group embraces Atlas Copco companies or agents manufacturing or selling and servicing Atlas Copco equipment in ninety countries throughout the world. For further details of the equipment featured here, contact your local Atlas Copco Company or Agent or write to Atlas Copco AB, Stockholm 1, Sweden.

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the closing spring in 25 sec., and the mechanism on normal service can complete an open-reclose-reopen cycle before it needs to wait for the spring to be reset. Alternatively, or in an emergency, this spring can be set by a removable handle. A smaller opening spring is automatically set by the operation of the closing spring.

All necessary safety relays and trips are housed in the circuit-breaker base.

The M.T. range includes two series, M and P, for medium and heavy breaking capacity respectively. They cover all recognised voltages from 10 to 45 kV, and have current ratings from 600 to 1,750 A up to 20 kV, 600 and 1,200 A at 30 kV, and 600 A at 45 kV. The P series has a rupturing capacity of 500 MVA (symmetrical) up to 20 kV, and 600 MVA for 30 and 45 kV. The M series has a rupturing capacity of 300 MVA (symmetrical) for all voltages. The breakers have been thoroughly type-tested according to I.E.C. standards by the Dutch official laboratory KEMA, and certificates of approval issued.

Scarpa & Magnano have recently published a booklet in English describing these circuit breakers and giving details, with oscillograph records, of the tests carried out at the KEMA Laboratory.

Surveying by the Tellurometer

For many years, survey instrument manufacturers have laboured to produce an instrument which would avoid the physical work of carrying a measuring tape along the ground to measure the distance between two points, and allow a greater accuracy than that provided by optical instruments now in general use. Thus the Tellurometer, which was demonstrated for the first time in London recently, attracted a good deal of attention. It was seen to have important applications in surveying, civil engineering and construction work of a major nature, such as hydro-electric schemes.

The invention of a South African, Mr. T. L. Wadley, of the National Telecommunications Research Laboratory, South African Council for Scientific and Industrial Research, the Tellurometer operates in the 10-centimetre waveband and measures the transit time of radio waves over the length to be determined, with an accuracy of a fraction of a millimicro-second. Measurements can be made by day or night and visibility is immaterial. In general optical line of sight is required over the length to be measured, and ranges of up to 20 miles or so are easily determined.

The accuracy readily obtainable is represented by an error of three inches at 10 miles, while a distance of 30 miles could be measured within six inches. Mr. Wadley said at the demonstration, which was held in Westminster, only two minutes away from the Offices of WATER POWER, that the Tellurometer could provide an answer in half an hour to a problem which, using more conventional methods of surveying, would normally take six qualified surveyors and 50 labourers from five to six weeks to complete.

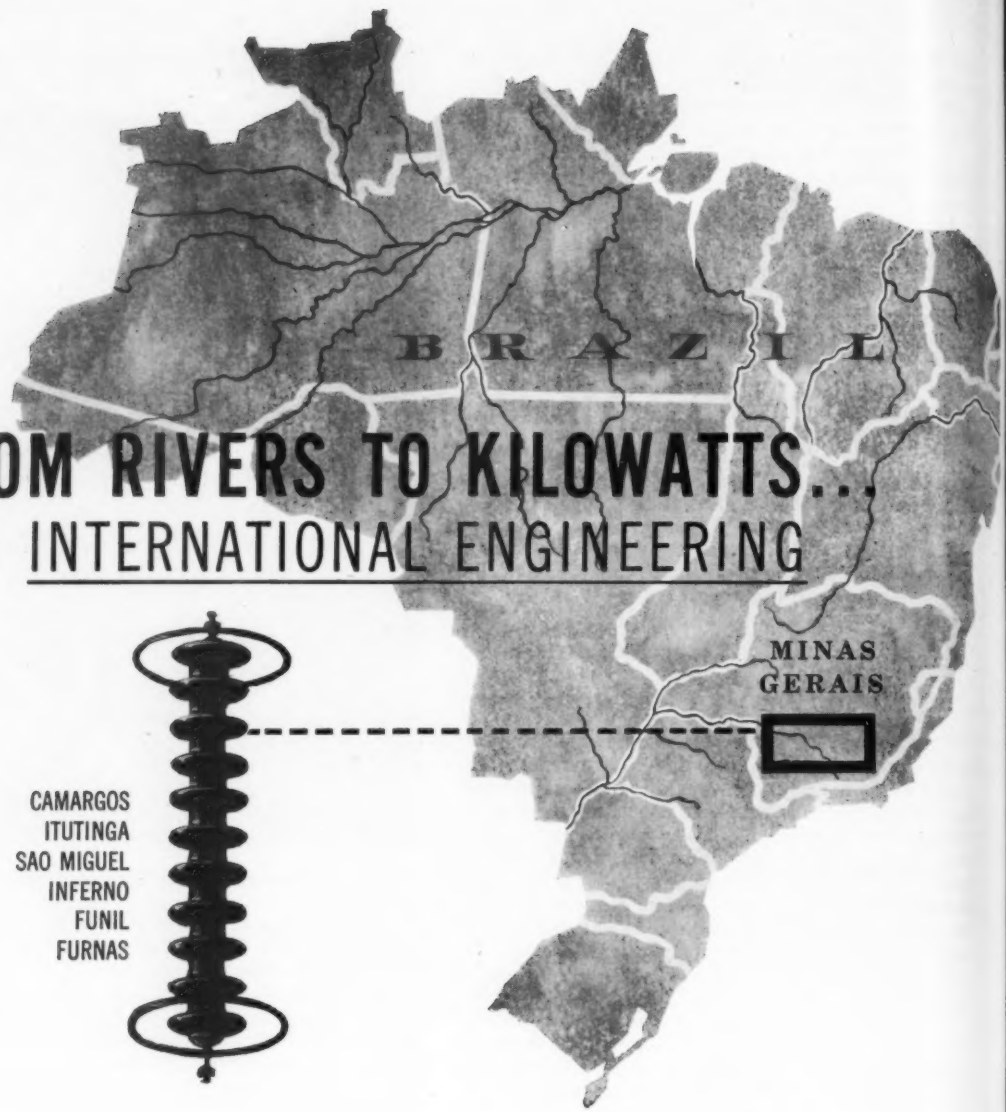
To measure a single line, one master and one slave station are necessary; if a number of remote stations are employed, a number of lines can be measured from the master station in the course of one setting up. A built-in duplex radio telephone circuit is included in the system and is used in the measurement procedure, which requires an operator at the master and remote stations.

The Tellurometer in service in South Africa

The Tellurometer, which is being marketed in Britain, Europe and all dependent Territories, India, Pakistan and Ceylon, by Cooke, Troughton and Simms, The Broadway, Westminster, has been described as "the most important development in surveying since the invention of the theodolite."

New Waterproofing Fabric

A new fabric designed for use as a reinforcing membrane for the coal-tar and asphalt compounds used in waterproofing and anti-corrosion applications is now being produced by Fothergill & Harvey (Sales) Ltd. Peter Street, Manchester 2. Known as "Tygascrim" this is an open-weave fabric weighing only 2·2 oz. per sq. yard and is woven from glass yarns and coated to ensure maximum compatibility with coating compounds. Its tensile strength is 75 lb. per in. in both warp and weft directions and its bursting strength 140 lb. per sq. in. This high tensile strength is claimed to make it highly suitable for machine application to pipelines and, being woven from inorganic yarns, it does not rot or decay or carry moisture into the waterproofing compound. This last feature is due to the non-wicking properties of the glass filaments and has a further advantage in that the



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fabric does not conduct vaporisable oils to the surface, thus preventing drying out of the compound.

The fabric is available with two types of coating which are applied to give complete compatibility with the type of coating compound being used, and, by binding the individual yarns in position, to make for much easier handling during coating operations. Type Y464B fabric is coated with a balanced asphalt-resin combination and may be used with both coal tar and asphalt base compounds. Type Y464C has a coal tar binder which creates an exceptionally strong bond with coal tar and epoxy-coal tar compounds. Both types of fabric have a pick-up factor of approximately 424 per cent.

Resumption of North Wales Scheme

Model of the Blaenau Ffestiniog 300 MW pumped-storage scheme, showing the upper reservoir at Llyn Stwlan, the lower reservoir formed by damming the Afon Ystradau, and the power station

On April 13th last the Member of Parliament for Merionethshire, Mr. T. W. Jones, and Mr. A. R. Cooper, the Divisional Controller of the Central Electricity Authority's North West, Merseyside and North Wales Division, inaugurated the resumption of work on the £15,000,000, 300 MW pumped storage scheme at Blaenau Ffestiniog, North Wales.

The scheme comprises an upper reservoir created by the enlargement of the small lake of Llyn Stwlan, while the lower reservoir will be created by damming the Afon Ystradau, at a level 1,000 ft. below the upper reservoir. The generating and pumping station will be constructed on the west bank of the lower reservoir.

The enlargement of Llyn Stwlan will be carried out by the construction of a concrete dam some 90 ft. high and 1,100 ft. long, on the eastern side of the existing lake. It will be of the massive buttress type.

The water will be handled to and from the reservoir by two vertical shafts, 700 ft. in depth and connected with two horizontal tunnels which will emerge from the hillside a short distance above the generating station on the lower reservoir. From the portal of the tunnels, four 8 ft. diameter steel pipes will carry the water to the generating station.

The generating plant will consist of four 75 MW units, manufactured by The English Electric Co. Ltd., each comprising a water-turbine generator and pump, on a vertical axis. Some two-thirds of the whole of the generating station will be below ground level. The transformers and high-voltage switchgear to couple the station to the Authority's 275,000 V super-grid system will be situated behind the generating station.

It is expected that when the scheme is completed, in 1961, the lower reservoir will be full from 4 p.m. to 9 p.m. daily, and by 6 a.m. the following morning it will be drawn down to its lowest level, and the upper reservoir will be full. At about 8 a.m. the generating station will draw water from the upper reservoir, and the lower reservoir will be half-full by 10 a.m. with all the exposed foreshore submerged. By 4 p.m. the daily cycle will be completed.

The photograph of a model which has been constructed shows the two reservoirs, the pipeline and power station.

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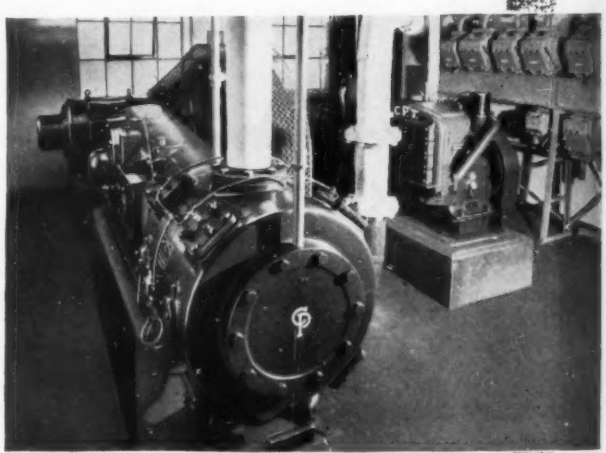

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Abstracts from the World Technical Press

West-European Power Co-ordination

A general survey is given of the activities of the UCPTE (Union pour la coordination de la production et du transport de l'Electricité) which was founded in Paris in 1951 under the patronage of O.E.E.C. Council, with the participation of Belgium, France, Italy, Luxemburg, Holland, Austria, Switzerland and Western Germany. The Union is actually a body of individuals acting as the delegates of the leading power concerns of the various countries and has now 28 ordinary and 11 extraordinary members. In addition to a schematic plan of the interconnected West-European systems, a graph gives the monthly amounts of energy exchanged in 1955 by the various countries. Details of the interconnected transmission lines are given in a table. (Dr. L. Bauer, Vienna, *OZE, Oesterreichische Zeitschrift für Elektrizitätswirtschaft*, Vol. 10, No. 3, March 1957, p. 84. 7 pp., 5 ff.)

Testing HT Circuit-Breakers

When designing a major power system, it is of economic importance, from the insulation aspect, to select circuit-breakers which do not cause excessively high over-voltages when being operated. This article gives a description of the 380 kV and 200 kV ASEA air-blast circuit-breakers of the HTFYD type, and an account of the field tests to which they were submitted in the network of the Swedish State Power Board. The main characteristics of the two circuit-breakers instanced are as follows:—Rated Voltage, 380 kV, 200 kV; Rated Service current, 1,200 A, 1,200 A; Rated Pressure, 215 p.s.i., 215 p.s.i.; Power breaks per phase, 12,8; Rated breaking capacity at 405 kV and P.F., 0·15 (inductive): Symmetrical breaking current (corresponding to 12,000 MVA), 19·8 kA (corresponding to 6,000 MVA), 17·3 kA; Asymmetrical breaking current, 24·3 kA, 21·3 kA; Opening time, 0·045 sec., 0·045 sec. (R. Engström and L. R. Bergström, *ASEA Journal*, Vol. 29, 1956, No. 11/12, p. 139, 10 pp., 11 ff.)

Solving Hydraulic Problems by Hydro-electric Differential Analysers

The use of automatic computers in the analysis of hydraulic projects is discussed in this paper, stress being laid on the suitability of the mechanical differential analyser of the ball-and-disc type when tackling problems which arise in hydro-electric systems. The programming of this type of analyser for the solution of general hydraulic problems is described, and the author shows how the results obtained may be used to determine the optimum design features. One of the problems worked out by means of the C.S.I.RO. differential analyser of the Mathematical Instrument Section, Sidney University, was the Tooma River diversion, which is part of the Snowy Mountains scheme, N.S.W. This investigation is reviewed at length as a typical example. The paper is reproduced in French and English. (H. K. Messerle, A.M.I.E., Australia, *La Houille Blanche*, No. 11, No. 6, December 1956, p. 813, 24 pp., 9 ff.)

Earth Dam Design in Western Canada

This paper discusses briefly some major points in the design and construction of earth dams, with particular emphasis on problems encountered by the Prairie Farm Rehabilitation Administration (P.F.R.A). in Western Canada. An attempt is made to cover important recent developments rather than repeat information available in existing texts. The paper is divided into three main sections: Geology; Design, with paragraphs on seepage control, pervious foundation, sheet-pile and concrete cut offs, abutments, stability, methods used for stability studies, factor of safety, settlement, slope protection, and embankment chacks; Construction, with paragraphs on foundation treatment, placement of impervious and pervious embankment material, test apparatus, and stage construction. Typical cross-sections of existing and proposed dams are shown, and a bibliography covering 43 references is appended. (R. Peterson, M.E.I.C., *The Engineering Journal*, February 1957, p. 129, 9 pp., 9 ff.)

A Nepalese Project

Four U.S. hydraulic experts, called in by the Nepalese Government, have declared feasible the Kosi River multi-purpose project, as drawn up by Indian engineers, and work has started on the taming of the river which rises in Tibet, flows through Nepal and Bihar, and annually floods the North Bihar plains. A total of 50 miles of earth embankment has already been completed by local unskilled labour. An outstanding feature of the scheme is the Hanumannagr dam near the Nepal border and 30 miles below the Chatra gorge; this structure, 1 mile long and 50 ft. high, will have two spillway sections, the main one 3,190 ft. in length. The power house, operating from a 21 ft. head, will have an initial capacity of 13,200 kW, to be ultimately increased to 21,000 kW. (*Engineering News-Record*, Vol. 158, No. 7, February 14, 1957, p. 66.)

Winter Concreting

The bearing of this article is markedly emphasised by the fact that its author is no less than the Senior Editor of the undermentioned journal for Rivers and Water Use. The prime case in point is that, at the beginning of March, there were "16 units of snow-covered inactivity" on the United States half of the St. Lawrence dam while its Ontario half swarmed with workers, as has been the case all the winter apart from one day in January when the thermometer in Cornwall went down to 40-50 below zero. Hence the question arises, why do Canadians place concrete in winter and U.S. engineers not do so. The Canadian reason is not a single, simple answer; many things are involved, the main one being that a stoppage during four months of hard winter would lose one third of every construction year. It is for this reason that Canadian experts have exerted themselves to solve all the questions relating to the placing of concrete in severe winters. In particular they know that a mass of curing concrete can pretty well take care of its own temperature in moderately cold weather; they have

checked this out on 3 ft. test cubes with thermocouples installed at measured points throughout and know that the heat of hydration generated in the inner mass warms nearly the whole block. They also know that if concrete is placed adequately heated, heat from within can get to the centre of each face of the cube in such quantity as to make ¾ in. plywood forms all the protection needed against freezing in the critical first 24 hours. Some of the reasons why U.S. dam-builders do not follow the Canadian example are implicit in differences in employment and economic conditions; there is a lot in the fact that the Canadian worker sticks to his job in winter because he has hardly any chance of finding work under less severe weather conditions, while his American colleague can almost always "go south" if he chooses. The author appears to accept as valid the American reluctance to adopt the high lifts now being used so effectively by the Canadians but asks whether they are sufficient to justify so great a divergence of method. (Arthur J. Fox, Jr., *Engineering News-Record*, Vol. 158, No. 10, March 7, 1957, pp. 23/25, 2 ff.)

Note: This article is supplemented by an inset (pp. 24/25) describing in detail the procedures applied by Ontario Hydro's concrete technicians at St. Lawrence Power Dam.

Steel-Concrete Seal under Dam

A description is given of the method adopted at the Swift project on the Lewis river, Washington, to provide a positive seal under the rock and earthfill dam 510 ft. high, 2,000 ft. long and 2,100 ft. thick at the base. Some 63,000 linear ft. of H-beams and sheet piling weighing 1,258 tons are going in upright for the cut-off. Sheet piling is welded to each flange of the H-beams and interlocked as each set is driven to bedrock. These form a row of 18 x 15 in. steel cells from which ground material is jetted out with air and water. Concrete is then poured into the cells to form a tight seal across the riverbed. (*Engineering News-Record*, Vol. 158, No. 12, March 21, 1957, p. 94, 1 f.)

Tetrapods in Breakwater Structures

Pre-cast concrete tetrapods, first used about 10 years ago by the Neyrpic Laboratory at Grenoble, have now found their way across the Atlantic. This article describes how four-legged concrete blocks, weighing each 25 tons and standing 10½ ft. high when resting on three legs, are cast and placed in the breakwater at Crescent City, Calif. Concrete is poured in 2 ft. lifts into steel forms from a 4 cu. yd. bucket, each lift being compacted by a pneumatic vibrator. When ready for use, the tetrapod is hoisted into a heavy rear-dumping truck for transport to the breakwater, where a crawler crane handles it. (*Engineering News-Record*, Vol. 158, No. 12, March 21, 1957, p. 46, 5 pp., 13 ff.)

Designing Future Transmission Systems

New voltages, new structures, new construction materials and new concepts are being tried out to meet the greater need for lower costs, and higher capacities for power transmission systems. This special report, prefaced by Dan Braymer, Assistant to the Editor of the undermentioned journal, reviews some of these design departures in the four following articles: (1) *Narrow-Base Steel Towers Designed for New 345-kV Line*, by A. C. Verock and R. G. Patrick, p. 92, 4 pp., 7 ff. Light-weight steel towers, bundled conductors and restrained middle-phase insulator strings are features of this design which is now being developed for the heavily loaded areas in the midwest. (2) *Design 230-kV Wood H-Frame Line for St. Lawrence*, by R. E. Moran, p. 96, 2½ pp., 3 ff. This line, which eliminates all dead-end structures, is based on "flexible design" using spar-type wood H-frames: reliability is a prime requisite. (3) *69-kV Section to Obtain 161-kV Single-Pole Line Data*, by L. A. Potter, pp. 98/99, 1 f. This is an experimental section of single-pole structures built by the Salt River Power District with wishbone-type cross-arms to secure data on a design that would conserve expensive right-of-way. (4) *230-kV Tower Design Requires Less Steel*, by Thomas M. Austin, p. 100, 3 pp., 3 ff. Reduction of undulation level and acceptance of a higher estimated flashover rate have enabled smaller and lighter towers to be used for heavy loading conditions, resulting in a saving in steel of up to 23·6%. This 83-mile line of the Bureau of Reclamation has had no lightning outages since it was put into service last November. (*Electrical World*, Vol. 147, No. 10, March 1957, p. 91.)

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Announcements for this column can be accepted up to the 8th of the month for the following month's issue. The charges are fourpence per word with a minimum of 10s. Box No. facilities 2s. 6d. extra. In order to avoid accountancy it would be appreciated if instructions to insert were accompanied with remittance.

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